3D VISUALIZED BRAIN MAPPING AND EEG SPIKE DETECTION

WITH WAVELET ANALYSIS

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3D VISUALIZED BRAIN MAPPING AND EEG SPIKE DETECTION WITH WAVELET ANALYSIS

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ABSTRACT

The EEG has become one of the most important diagnostic tools in clinical neurophysiology. However, EEG analysis still relied mostly on its visual inspection. Due to the fact that visual inspection is hardly allow any statistical analysis or standardization, several methods were proposed in order to quantify the information of EEG. Among these methods, the Fourier Transform emerged as a very powerful tool capable of characterizing the frequency components of EEG signals. Fourier Transform has some disadvantages that limit its applicability and therefore, other methods for extracting hidden information from EEG are necessary.

The objective of this research is to develop off-line monitoring software for comparing methods of EEG signal analysis, Fast Fourier Transform, Short Time Fourier Transform (Gabor Transform) and B-Spline Wavelet Transform. The results form these analysis methods will be presented as 2D and 3D brain mapping and will be computed to detect EEG spike. The software was developed using Microsoft Visual Studio 2003, C#.Net and DirectX9.0C.

Finally, the software can enable users to scan and detect spikes, display spectrums on 3D scalp model and also allow users to play and study the hidden information from all provided time-frequency analysis methods. The result Time-frequency resolution achieved with Wavelet Transform allowed a very detailed study of the time evolution of the frequency peaks during the seizure. This result is in agreement with the described with Gabor Transform.

KEY WORDS : EEG/ ELECTROENCEPHALOGRAM/ TOPOGRAPHIC / WAVELET/ 3D BRAIN MAPPING

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การแสดงแผนที่การทำงานของสมองสามมิติ พร้อมกับการตรวจหาคลื่นผิดปกติด้วยวิธีวิเคราะห์แบบเวฟเลต (3D VISUALIZED BRAIN MAPPING AND EEG SPIKE DETECTION WITH WAVELET ANALYSIS)

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บทคัดย่อ

การบันทึกค่าและแสดงผลคลื่นสัญญาณสมอง EEG เป็นวิธีวินิจฉัยโรคทางระบบชีวประสาทที่มีความสำคัญมาก แต่การวิเคราะห์สัญญาณ EEG โดยส่วนใหญ่ ยังต้องใช้ผู้มีประสพการณ์วิเคราะห์ด้วยสายตา ซึ่งไม่เหมาะสำหรับการใช้อ้างอิงทางสถิติ หรือใช้เป็นมาตรฐานที่มีความแม่นยำแน่นอนได้เสมอไป จากเหตุผลนี้ จึงมีผู้พยายามใช้วิธีการคำนวนทางคณิตศาสตร์เข้ามาช่วยในการวัดและวิเคราะห์ข้อมูล วิธีที่มีบทบาทสำคัญในการอธิบายคลื่นความถี่ต่างๆ ในสัญญาณ EEG ได้แก่ Fourier Transform แต่เนื่องจาก Fourier Transform ยังมีข้อจำกัดบางประการ ทำให้จำเป็น ต้องศึกษาและ หาวิธีการอื่นเพิ่มเติม สำหรับนำมาใช้อธิบายคลื่นความถี่ต่างๆ ที่อยู่ในสัญญาณ EEG

ดังนั้น วัตถุประสงค์ของการวิจัยครั้งนี้ ก็เพื่อที่จะพัฒนาโปรแกรมสำหรับอ่านข้อมูลสัญญาณ EEG และเปรียบเทียบการคำนวนทางคณิตศาสตร์ต่างๆ ที่จะนำมาช่วยวัดและวิเคราะห์ข้อมูล วิธีที่จะนำมาเปรียบเทียบได้แก่ฟาสต์ฟูเรียร์ทรานสฟอร์ม ชอร์ตไทม์ฟูเรียร์ทรานสฟอร์มหรือเรียกอีกชื่อว่ากะบอร์ทรานส์ฟอร์ม และบี-สไปน์เวฟเลตทรานสฟอร์ม ผลที่ได้จะนำมาแสดงในรูปแผนที่การทำงานของสมอง 2 มิติ และ 3 มิติ รวมถึงจะนำมาคำนวนหาคลื่นสัญญาณสมองผิดปกติ โปรแกรมนี้ถูกพัฒนาบน Microsoft Visual Studio 2003 โดยเขียนด้วยภาษา C#.Net และใช้งานร่วมกับ DirectX9.0C

ทั้งนี้โปรแกรมที่พัฒนาสำเร็จแล้ว สามารถตรวจหาคลื่นสัญญาณสมองผิดปกติและสามารถแสดงแผนที่การทำงานของสมอง 2 มิติ และ 3 มิติได้ รวมถึงสามารถใช้ทดสอบผลที่ได้จากวิธีการคำนวนทางคณิตศาสตร์ต่างๆ เพื่อเปรียบเทียบประสิทธิภาพในการวัดและวิเคราะห์ข้อมูลสัญญาณ EEG ซึ่งผลจากการเปรียบเทียบพบว่า บี-สไปน์เวฟเลตทรานสฟอร์ม ให้ข้อมูลตำแหน่งยอดคลื่นตามเวลาที่เปลี่ยนไปอย่างละเอียดและสามารถนำมาใช้อธิบายร่วมกับกะบอร์ทรานส์ฟอร์มได้

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CHAPTER I
INTRODUCTION

1.1 Introduction

The Electroencephalogram (EEG) is important clinical data that enable a brain specialist to analyze functional disorders of the brain. In general, analysis methods of EEG are classified into two types. One is a signal processing method that has been used in clinical area. The other is a topographic map that is analyzed to use a graphical description. In this description, human scalp is projected onto geometrical modeled plane or space (1).

Until now, the EEG analysis is largely dependent on the signal processing method. But, this method is very difficult and complex, so only EEG technician with special educational background is able to analyze the EEG. Because of this reason, many engineers in medical imaging and EEG areas have been studying graphical method. The early trial, which is mapped in a plane (2D), had been studied, and this result was partly adopted in clinical area. But, 2D methods make it impossible to analyze an interesting area in 3 dimensions, so the analysis using 2D methods never localize an area of a functional disorder of the brains. To overcome these disadvantages, 3D methods have been studied, and it was proved that 3D methods are efficient. (1)

Two main advantages are as follows:

First, the distortion introduced by projecting a curved surface onto a plane is completely eliminated. Second, the possibility of rotating the object before presenting it on the screen provides the advantage to select regions in the scalp where the most interesting electric phenomena appear, according to the kind of data being analyzed.

1.2 Problems

- The researches about EEG signal analysis are always done on mathematical software, which require that mathematic software environment on end user's PC. Those researches cannot be used in real world. Because almost of them are done on mathematic software
- None of 3D topographic software is developed in Thailand. Currently, many applications are donated from abroad. And Thai worked as their software tester.

1.3 Objectives

- To create software that presents the EEG signal in 3 dimensions.
- To create software that has ability to add more analyzing functions to analyze other symptoms in future study.
- To implement an analyzing function that can detect the abnormal EEG spike.

1.4 Scope of Work

The scopes of the study are focused on:

- Study of all EEG environment variables, which the software can calibrate for accuracy analyze. The variables are categorized in electrode system, montages style, sampling rate, etc.
- Study and implement Gabor Transform, Wavelet transform etc. into an application.
- Design software to be easy-addition for new functions into the software.
- Study EEG data and design algorithm for spikes detection.
- 2D and 3D Topographic programming.

CHAPTER II
LITERATURE REVIEW

2.1 Basic Principles of EEG Mapping

The background electrical activity of the brain in unanesthetized animals was described qualitatively in the nineteenth century, but it was first analyzed in a systematic manner by the German psychiatrist Hans Berger, who introduced the term electroencephalogram (EEG) to denote the potential fluctuations recorded from the brain.

When we make records of potential differences between an exploring electrode resting on the cortical surface and a distant reference electrode, we are in effect recording the resultant field potential at a boundary of a large conductile medium containing an array of active elements. It is evident of the electrophysiology of the cortex. Any electrical changes recorded at the surface are due to the orderly and symmetric arrangement of some classes of cells within the cortex.

Electrical recordings from the exposed surface of the brain or from the outer surface of the head demonstrate continuous oscillating electric activity within the brain. Both the intensity and the patterns of this electric activity are determined to a great extent by the overall excitation of the brain resulting from functions in the brainstem reticular activating system. The undulations in the recorded electric potentials are called brain waves, and the entire record is called an electroencephalogram (EEG).

The intensities of the brain waves on the surface of the brain (recorded relative to an indifferent electrode such as the earlobe) may be as large as 10 mV, while the waves recorded from the scalp are approximately 100uV. The frequency of these brain waves range from 0.5 to 100 Hz, and their character is dependent on the degree of activity of the cerebral cortex (2).

2.1.2 Electrode System

The system most used to place electrodes for monitoring the clinical EEG is the International Federation 10-20 system shown in Fig. 1. This system uses certain anatomical landmarks to standardize placement of EEG electrodes (2).

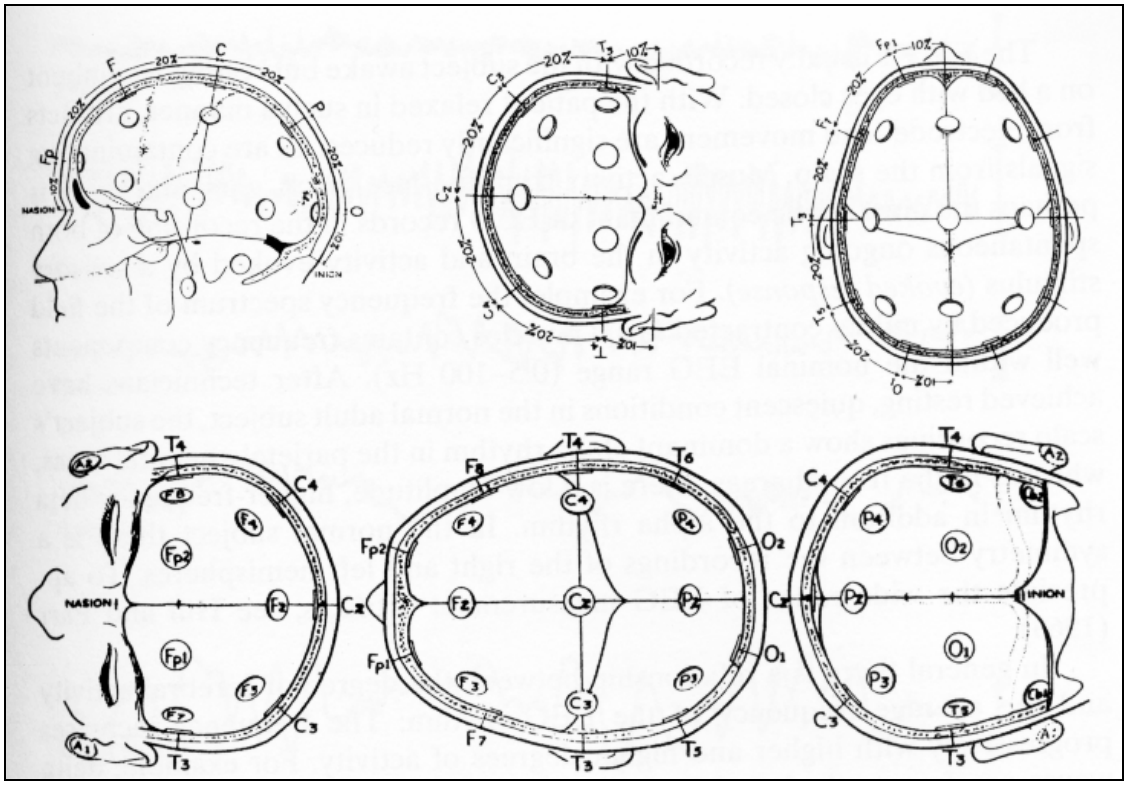


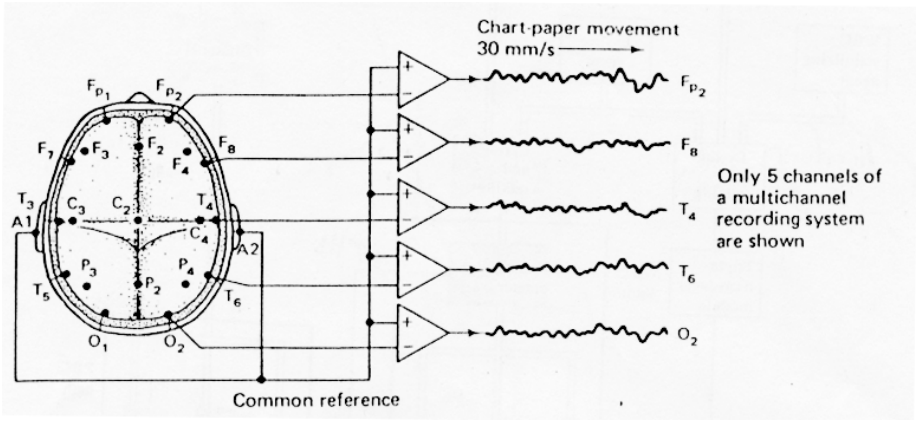
Figure 1. The 10-20 electrode system This system is recommended by the International Federation of EEG Societies. (2)

It should be noted that highest number of electrode at present is 128 channels because of limitation on a distance between electrode should be 2-2.5 cm. and using 45 min to fix all electrode which almost impossible to use in a clinical setting (3).

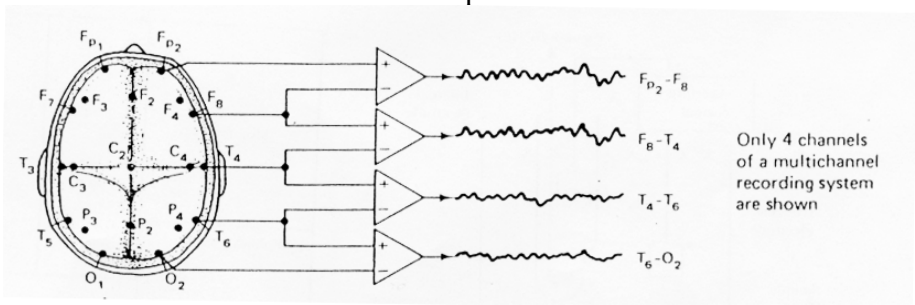
2.1.3 Reference Electrode

The differential amplifier requires a separate ground electrode plus differential inputs to the following three types of electrode connections; 1.Between one monopolar lead and a distant reference electrode (usually attached to one or both earlobes), 2.

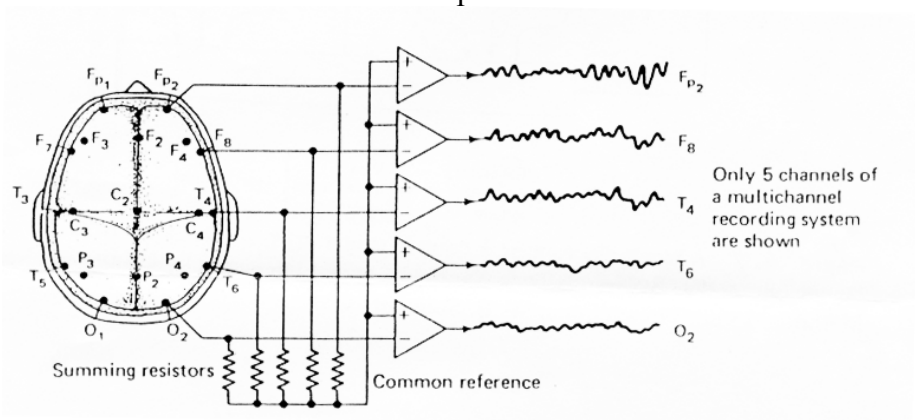
between each member of a pair (bipolar), and 3. between one monopolar lead and the average of all.



a. Unipolar



b. Bipolar



c. Avarage

Figure 2. Three amplifier modes for recording the EEG. There is an international standard placement for the electrodes. The letters indicate brain lobes or area: F is frontal, C is central, P is parietal, O is occipital, and T is temporal. (From Strong, P. 1970. Biophysical measurements. Beaverton, OR: Tektronix.) (4)

Figure 2 shows 3 amplifier modes for EEG recording. In the average reference mode, the system reference is formed by connecting all scalp-recording locations through equal high resistances to a common point. In the bipolar system, differential measurements are made between successive pairs of electrodes. The advantage of using a differential recording between closely spaced electrodes (between successive pairs in the standard system for example) is cancellation of far-field activity common to both electrodes; one thereby obtains sharp localization of the response. Although the same electric events are recorded in each of three ways, they appear in a different format in each case. The potential changes that occur are amplified by high gain, differential, capacitively coupled amplifiers. The output signals are usually displayed via ink-writing strip-chart recorders, a method that usually limits the frequency response to the range of 0.5-80 Hz (2), (4).

2.1.4 Montages

The particular arrangement whereby a number of different derivations is displayed simultaneously in an EEG record is termed a *montage*. The main reason for using different montages is to make EEG interpretation as easy and accurate as possible. For this purpose, certain guidelines have to be followed, and the American EEG Society has given some recommendations in this regard. (5)

Table 1. Recommended Montages format by the American EEG Society

(A) Longitudinal Bipolar	(B) Transverse Bipolar	(C) Referential w/earlobes
Fp1 – F7	F7 – Fp1	F7 – A1
F7 – T3	Fp2 – F8	T3 – A1
T3 – T5		T5 – A1
T5 – O1	F7 – F3	
	F3 – Fz	F8 – A2
Fp2 – F8	Fz – F4	T4 – A2
F8 – T4	F4 – F8	T6 – A2
T4 – T6		
T6 – O2	T3 – C3	Fp1 – A1
	C3 – Cz	F3 – A1
Fp1 – F3	Cz – C4	C3 – A1
C3 – T3	C4 – T4	P3 – A1
C3 – P3		O1 – A1
P3 – O1	T5 – P3	
	P3 – Pz	Fp2 – A2
Fp2 – F4	Pz – P4	F4 – A2
F4 – C4	P4 – T6	C4 – A2
C4 – P4		P4 – A2
P4 – O2	T5 – O1	O2 – A2
	O2 – T6	

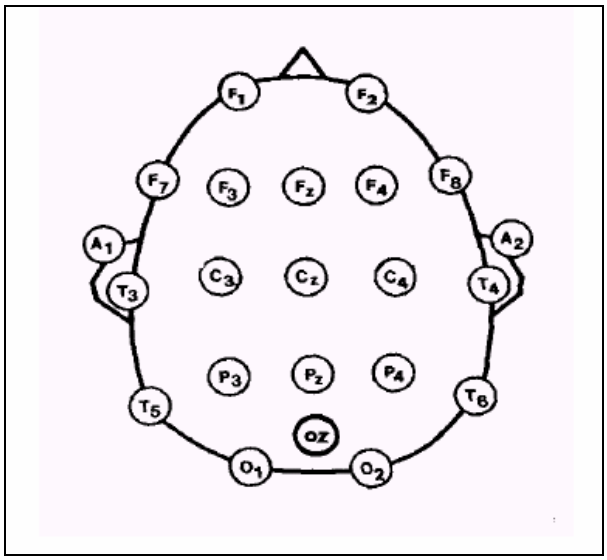


Figure 3. The 10-20 electrode system for compare with Montages formats in table 1

2.1.5 Reformatting of Montages

Recent advances in technology have afforded a means whereby the pattern of activity observed in one montage may be used to derive or predict the pattern of activity that would be seen in another.

A patient's EEG is recorded using a referential montage in which tracing from the 19 scalp electrodes are taken with respect to a common electrode. Each tracing shows the variation in voltage that occurs with time at a particular derivation. The voltages from two of electrodes are combined over time, the result would be a time-vary voltage like that observed in bipolar connection. This operation can be carried out for any two electrodes, and in this way a wide variety of montages can be created. So, the EEGer can reformat the record, later, into any numbers of different montages (5).

2.1.6 Topographic EEG analysis approach

In recent years, the advances of computer technology are rapidly grown along the microprocessor technology. Then, the using of computer systems in the clinical routine EEG laboratory is very favorable. These systems offer the possibility of data acquisition, editing and processing of data, artifact rejection, statistical analysis, and brain mapping. Brain mapping is the current name used for the methodology of representing the EEG activity, either spontaneous or evoked, in the spatial domain as a

topographic map projected onto the scalp. The feature represented may be an amplitude of a given peak, a spectral variable, or a correlation measure (6).

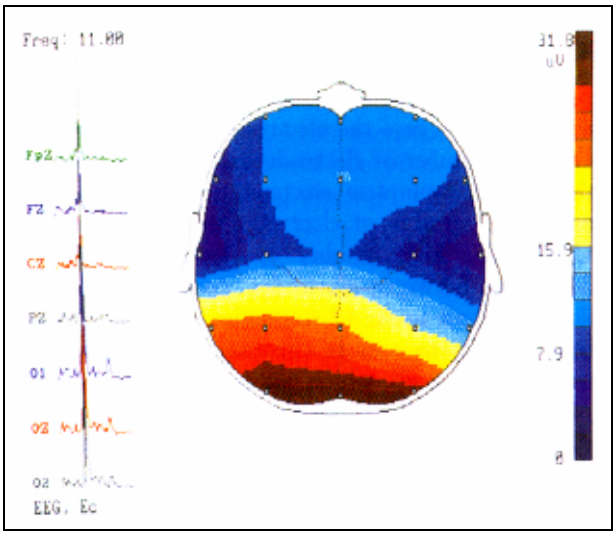


Figure 4. An Increase in activity with a midline maximum along transversal electrodes (3)

The choice of the reference electrodes affects the appearance of any brain map. Lehmann and Michel (1989) have advised the use of the average reference, since all other reference sited may be close to the site of a maximum or a minimum potential. A disadvantage of this system is that in the case of focal pathology, the potentials from the corresponding area may influence all recordings. Other system that is widely used is the linked earlobes reference. It is important to note that linked ears may yield distortion of a brain map because of possible difference in impedance between the two ears (as seen in figure 4). In these cases, it is advisable to add a high resistance between the ear electrodes to reduce such an effect. In fact, there is no ideal reference system. In general, a safe practice is to record the same data using several reference systems in order to determine how robust a particular brain map is (6).

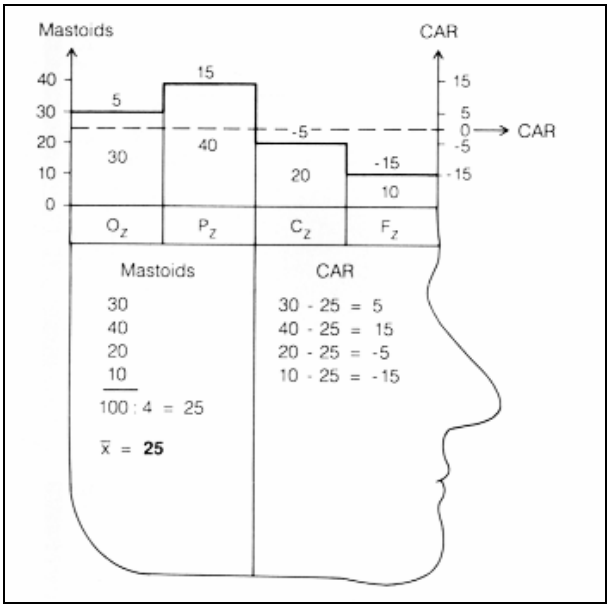


Figure 5. CAR technique

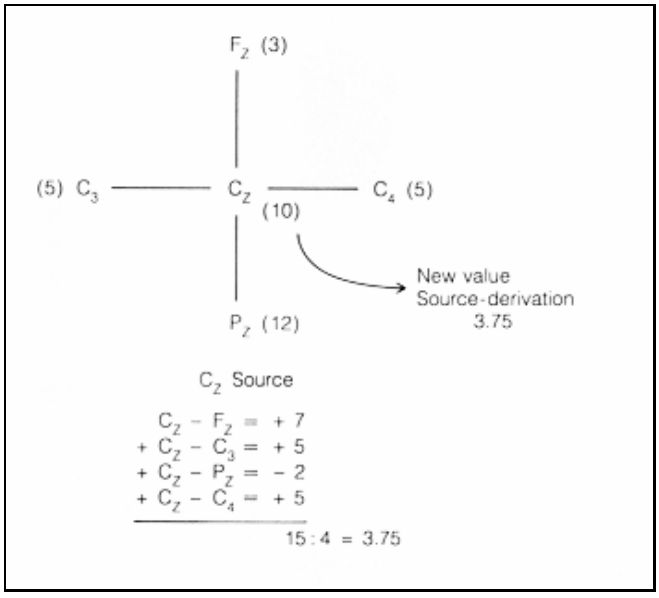


Figure 6. LAR technique

In order to obtain a more precise spatial representation of the brain potentials at the scalp, one could use the more sophisticated approach of the Laplacian operator. It should be realized that electric sources within the brain cause potentials at the scalp that are spread over a relatively large area, due to the volume conductor properties of the brain and surrounding tissues. Therefore, the potentials measured between any two sited over the scalp represent the summation of signals from many cerebral, and even

extracerebral, sources. The use of the Laplacian operator reduces the spatial blurring distortion at the scalp. The Laplacian operator is a mathematical procedure by means of which the potential at each electrode is converted to a quantity that represents the current density entering or leaving the scalp at that site. In this way, the need for a common reference electrode can be avoided. It should be noted, that the computation of the Laplacian operator also poses some problems (3), (6). Table 2 show various forms of EEG mapping that are in common used.

Table 2. Forms of computerized EEG/EP mapping (3)

EEG mapping in the resting state (awake) with eyes open or closed
EEG amplitude mapping (time domain): presentation of voltage parameters and their topography without FFT
Amplitudes of EEG waves (delta, theta, alpha, beta)
Amplitude of EEG pattern (e.g., spikes/wave complexs, sharp waves, K-complex, sigma spindles)
EEG frequency mapping (frequency domain): presentation of frequency Parameters and their topography after FFT
Spectra of EEG background activity (delta, theta, alpha, beta), presented as
a) bandpower (uV^2)
b) square root of power (activity in uV)
c) relative activity (percentage)
d) coherence function
EEG mapping in the activated state (dynamic EEG cartography)
Examples in the eyes-open state
Reading silently
Reading aloud
Studying figures, etc.
Examples in the eyes-close state
Finger movements(e.g., open and close fist)
Listening to speech
Listening to music
Calculation (e.g., 100 minus 7), etc.
EEG mapping during sleep
EP mapping
EP mapping (exogenous components)
Mapping of visual Eps
Mapping of auditory Eps
Mapping of somatosensary EPs
EP mapping (endogenous components)
Mapping of auditory, visual, and somatosensory P300
Mapping of contingent negative variation
Mapping of slow wave
Mapping of statistic parameters
Mapping of Z value
Mapping of t and p values
Mapping of correlations between parameters
Neurometric

2.1.7 EEG Reading

The International Federation of Societies for Electroencephalography and Clinical Neurophysiology has proposed definitions for the various terms used in EEG to facilitate communication between different eleoctroencephalographers. The following lists are some of the terms that are most commonly used in EEG reading (5).

2.1.7.1 Background Activity

This term denoted the general setting in which changes in frequency, amplitude, or morphology appears. Although the alpha rhythm may be the background activity in the tracings from the posterior regions, it is important to note that the term background activity is not synonymous with alpha rhythm; thus, the frontal area, the activity may be mostly in the beta frequency band. The background activity may not always be a normal pattern; the term can also refer to abnormal patterns.

Both the background activity and the changes that appear in the features of the tracing are described in terms of frequency, amplitude, wave shape, symmetry, synchrony, location, continuity, and reactivity.

2.1.7.2 Frequency

This term refers to the rate at which a particular waveform repeats; it is usually used in the context of rhythmic activity (repeating with regularity). Depending on the frequency, the activity is classified as delta (less than 4 Hz), theta (4 to 8 Hz), alpha (8 to 13 Hz), or beta (more than 13 Hz) activity.

The frequency bands are used to describe the activity irrespective of where it occurs. But the term alpha rhythm is more specifically used to denote the 8 to 13 Hz rhythm occurring during wakefulness over the posterior region of the head; it occurs generally with maximum voltage over the occipital area, is best seen with the patient's eyes closed and under conditions of physical relaxation and relative mental inactivity, and is blocked or attenuated by attention, especially visual attention and mental effort. Sometimes the terms fast and slow activity are used to denote a dominant frequency above or below the alpha band. The term *monorhythmic* is often used when the particular activity shows rhythmic components of a single frequency. When there are

multiple frequencies the term *polyrhythmic* is used. The term *periodic* applies to EEG waves or complexes recurring at approximately regular intervals; usually the intervals vary from one to several seconds.

2.1.7.3 Amplitude

The term amplitude is expressed in terms of voltage in microvolts based on a peak-to-peak measurement. One needs to know the sensitivity at which a recording was made to determine this. The amplitude will vary depending on the technique of recording, the bipolar montages with short interelectrode distances giving smaller a amplitude than the referential montages with larger interelectrode distance. Ideally, amplitude should be described in terms of the actual voltage; however, the terms low, medium and high amplitude are often used. The terms low is used when the amplitude is under 20 uV, medium when it falls in the range of 20-50 uV, and high for more than 50 uV. The use of these terms is discouraged owing to lack of uniform criteria.

Attenuation and blocking are terms used when there is a reduction in the amplitude of EEG activity, usually in response to some stimulus. The classic example is attenuation of the alpha rhythm in response to eye opening. The term suppression is used when little or no electrocerebral activity can be discerned in a tracing. Paroxysmal activity is a term denoting activity of much higher amplitude than the background that occurs with sudden onset and offset. It need not necessarily denote an abnormal activity.

2.1.7.4 Wave shape or Morphology

Electroencephalographic activity is essentially a mixture of waves of multiple frequencies. The appearance of the waveforms depends on the component frequencies, their relative voltages and phase relationships, and, of course, upon the frequency filters used. The waveforms are also continuously fluctuating in response to stimuli and depend on the state of the patient. Several descriptive terms may be used in this context.

A transient is an isolated wave that stands out from the background activity; if it has a sharply pointed peak and the duration is less than 70 ms (less than 2 mm at the paper speed of 30 mm/s) it is called a spike; when the duration is between 70 to 200 ms, it is called a sharp wave. The term complex is used when two or more waves occur together and repeat at consistent intervals; examples are spike and wave complex and sharp and slow-wave complexes. An activity is described as monomorphic when the morphology of subsequent waveforms is similar whereas the term polymorphic is used when they are of dissimilar morphology. The description should also include the number of phases. Thus, a wave may be monophasic (positive or negative) or diphasic (positive and negative), triphasic or polyphasic.

2.1.7.5 Symmetry

In general, symmetry refers to the occurrence of approximately equal amplitude, frequency, and form of EEG activities over homologous areas on opposite sides of the head.

2.1.7.6 Synchrony

This term refers to the simultaneous appearance of morphologically identical waveforms in areas on the same side or opposite sides of the head.

2.1.7.7 Location

Several different terms are used. Focal and localized are terms used when a particular activity is confined to one particular region of the head. For example, an activity may be localized to frontal, temporal, parietal, or occipital areas. The term generalized is used when activity is not limited to one region but occurs over a wide area. An activity is said to be lateralized when it is present on one side only.

2.1.7.8 Continuity

An activity may be described as continuous or intermittent, depending on the percentage of time it is present. Thus, an activity is called continuous when it occurs

without interruption for prolonged periods of time and discontinuous or intermittent when it appears only from time to time.

2.1.7.9 Reactivity

The term refers to alterations in the amplitude and waveform of activity in response to a stimulus. An example is the attenuation of alpha activity on eye opening.

2.1.8 Describing and Interpreting the EEG

An adequate and accurate description of the EEG record is important for several reasons. When a clinical would like to compare the EEGs from different laboratories the written description of the records is essential. It may be said that if the description is good, the EEGer can figure out the actual EEG record in his mind's eye. To make the description as objective and as accurate as possible, it is important to break down the complex tracing in terms of frequency, voltage, reactivity, synchrony, and distribution (5).

The various activities occurring in different states of consciousness, namely, wakefulness, drowsiness, and sleep, should be described clearly. Intermittent activity should be described in similar terms, including the location and synchrony. If sharp waves spikes, or other intermittent activity is present, it should be described in terms of location, polarity, and amplitude; how the activity is affected by changes in state should also be noted.

The basic question to ask after completing a visual analysis of the EEG is whether the findings are consistent with the accepted norms for the age and state of the patient. This means that the reader should have a through knowledge of the normal variations of EEG patterns in relation to age and state of the patient.

If the EEG is normal, the interpretation ends with a statement to that effect. If an abnormality is present, the next phase of interpretation involves categorization of the abnormality in more specific terms. If an abnormality is found to be localized, one needs to specify what area of the brain underlies the abnormality.

The next step in the interpretation is to suggest what kind of changes may be happening in the brain that could account for, or be compatible with, the abnormal EEG pattern. This entails a clear knowledge of the relationship between the various EEG abnormalities and the various disorders that affect the brain. One of the major problems in this aspect of interpretation is that many different types of disorders affecting the brain can give rise to the same type of EEG abnormality so that very often only general comments can be made. Following the technical interpretation, it is always useful to provide a clinical correlation on the basis of the patient's clinical history. Often it may be of value to say whether the EEG abnormality seen is consistent with the clinical diagnosis.

2.2 Epilepsy

2.2.1 International League Against Epilepsy classification of seizures

The ILAE classification of seizures is highly empirical and based on both the visible manifestations of the seizure and the EEG. The pathology, anatomical cause and underlying physiology are ignores. Three main categories are recognized: partial seizures, which are subdivided into simple and complex, generalized seizures, which are subdivided into convulsive and non-convulsive, and unclassified (7), (8).

2.2.1.1 Simple partial seizures

There is no alteration of consciousness during simple partial seizures, which may progress to become complex partial seizures. Both simple and complex partial seizures may also expand into secondary generalized seizures.

2.2.1.2 Complex partial seizures

Complex partial seizures are associated with an altered consciousness, defined as the inability to respond normally to exogenous stimuli by virtue of an altered awareness and/or responsiveness. However, this may be difficult to define in a given patient. Complex partial seizures have three components: aura, impaired consciousness, and automatisms

2.2.1.3 Generalized seizures

A generalized seizure is defined as an attack, which involves wide area of the cerebral hemispheres simultaneously from the onset, with no evidence of an anatomical or functional focus. Consciousness is almost invariably impaired and motor manifestations are nearly always symmetrical, with bilateral and grossly synchronous discharges over both hemispheres on EEG. There are two main types of generalized seizure: absence and tonic-clonic: with others including tonic, atonic and clonic convulsion.

2.2.2 Diagnosis of Generalized Epilepsy

There are two major types of primary generalized epilepsy, namely, absence (petit mal) and tonic-clonic seizures (grand mal). Interictal are extremely important in the diagnosis of these disorders, as ictal patterns may not occur during routine EEG recording (9).

2.2.2.1 Absence Seizures (Petit Mal Epilepsy)

Consist of a sudden lapse of consciousness with impairment of mental functions. They last about 5-20 seconds and the EEG is characterized by generalized 3 Hz spike wave discharges (a spike followed by a slow half period oscillation). The rate of the spikes may vary from 2½ to 4 Hz; the highest amplitude is in the frontal area, although rarely it may occur in the occipital area instead. The discharges may last from one to several seconds. Although discharges of very brief duration (< 3 seconds) are considered interictal and prolonged discharges ictal, the distinction is rather nebulous and depends on the feasibility of detecting changes in level of consciousness within very short intervals of time. Prolonged discharges lasting 12 seconds or more often lead to automatisms and confusional states. A characteristic feature of absence seizures is the ease with which they can be brought on by hyperventilation (Figure 7) (5),(9).

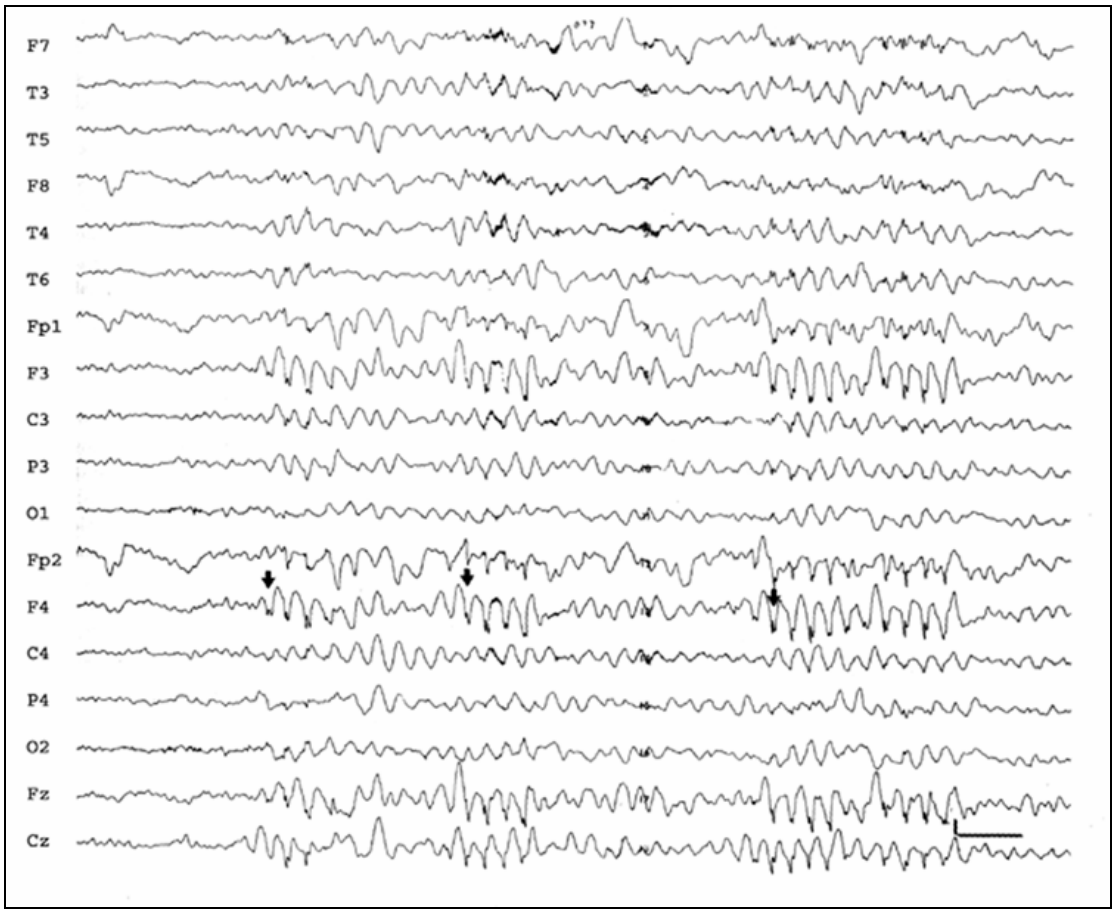


Figure 7. Generalized 3-Hz spike and wave discharges. Arrows point to several of the spikes. Filters: low frequency=1Hz, high frequency=70Hz. Calibrations: horizontal=1second, vertical=50uV. (5)

2.2.2.2 Tonic-clonic seizures (Grand Mal Epilepsy)

A tonic-clonic (Grand Mal) seizure normally lasts about 40-90 sec and it is characterized by violent muscle contractions. An initial tonic phase with massive spasms (i.e. extreme muscular tension without movement) is supplanted some seconds later by the clonic phase with violent flexor movements and characteristic rhythmic contractions of the entire body until the ending of the seizure. During these seizures consciousness is impaired.

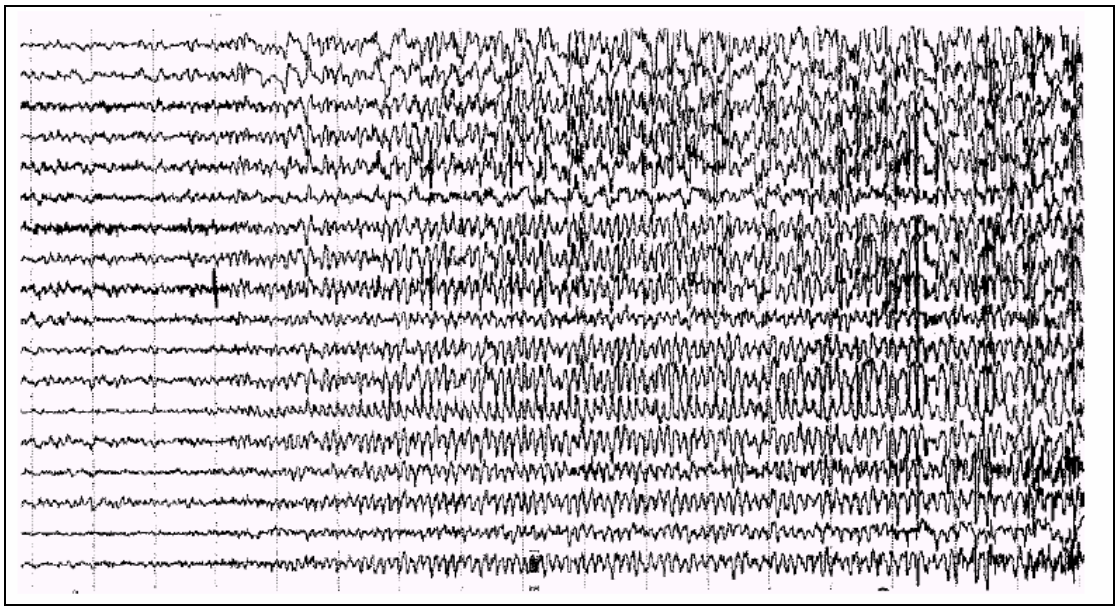


Figure 8. Tonic-Clonic seizures, note how the artifacts obscure the recording completely. (9)

Visual inspection of scalp recordings of these events is often troublesome because the signal is obscured by muscle artifacts (see figure 8). In most cases the analysis is confined to the interpolation of electrical abnormalities that either precede or follow the tonic-clonic activity, thus neglecting the ictal phase (5),(9).

2.3 Signal Analysis

The most signals in practice are time-amplitude representation signals. This form of signals often gives un-enough information to analyze or study. With applying mathematic transform, the signal data will be presented in different way and the hiding information will appear. Among many kinds of information in signal, the frequency representation is the most powerful and standard one. Frequency spectrum information usually helps the researchers to understand physical phenomena. The Fourier transform, developed by Jean Baptiste Fourier (1768-1830), is used to transform signal in time domain to frequency domain.

2.3.1 Fourier Transform

The raw signal in time domain is a continuous sum of sinusoids of different amplitudes, frequency, phases. For samples, please see in picture below;

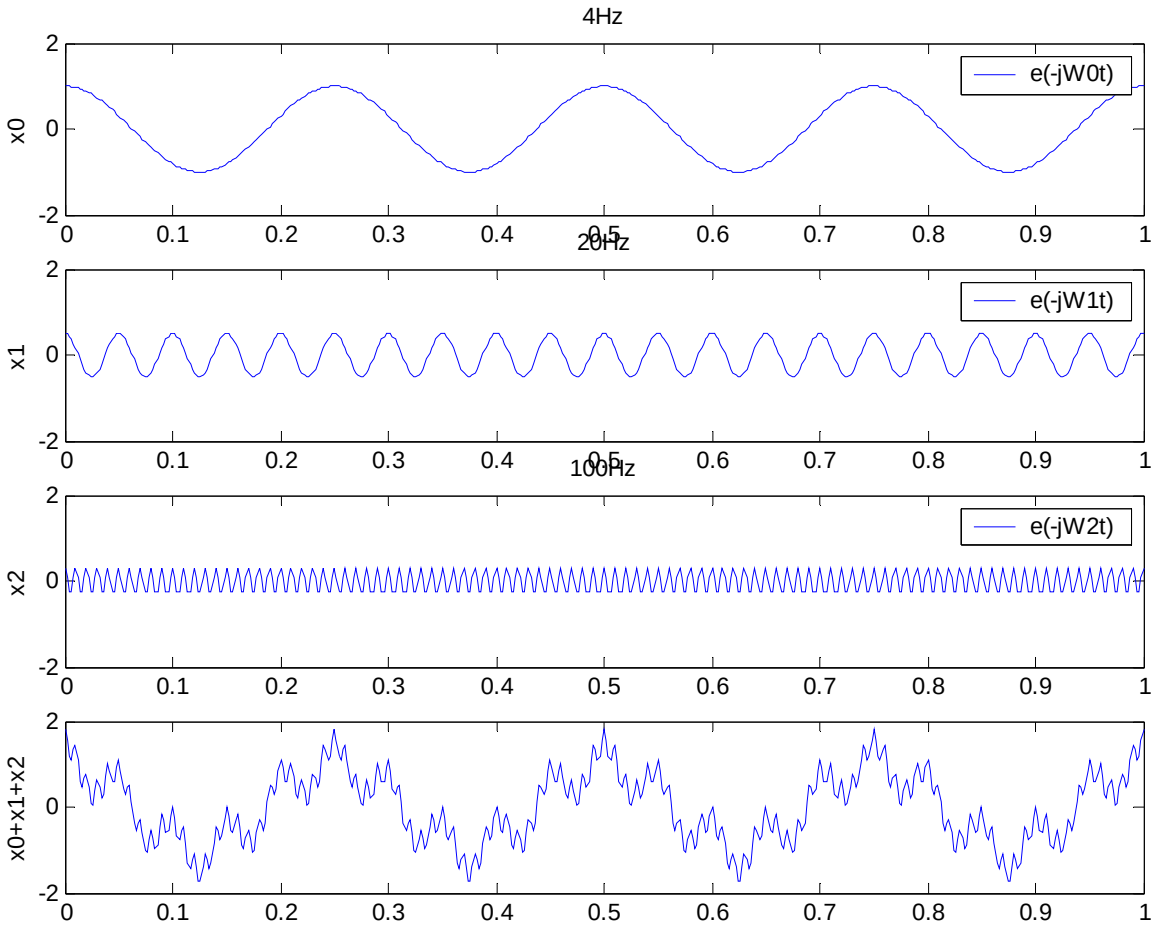


Figure 9. 3-frequency combined signal

The first three signals, x0, x1 and x2 can be mix together. The output result, of x0+x1+x2, is the signal on the last graph. From Fourier equation,

$$x_t = C_0 e^{-j\omega_0 t} + C_1 e^{-j\omega_1 t} + C_2 e^{-j\omega_2 t} + \ldots\ldots + C_\infty e^{-j\omega_\infty t} \quad \text{(ft1.)}$$

If x0 = C0e-jw0t,
x1 = C1e-jw1t,
x2 = C2e-jw2t,

So, we can plot C0-C∞ as;

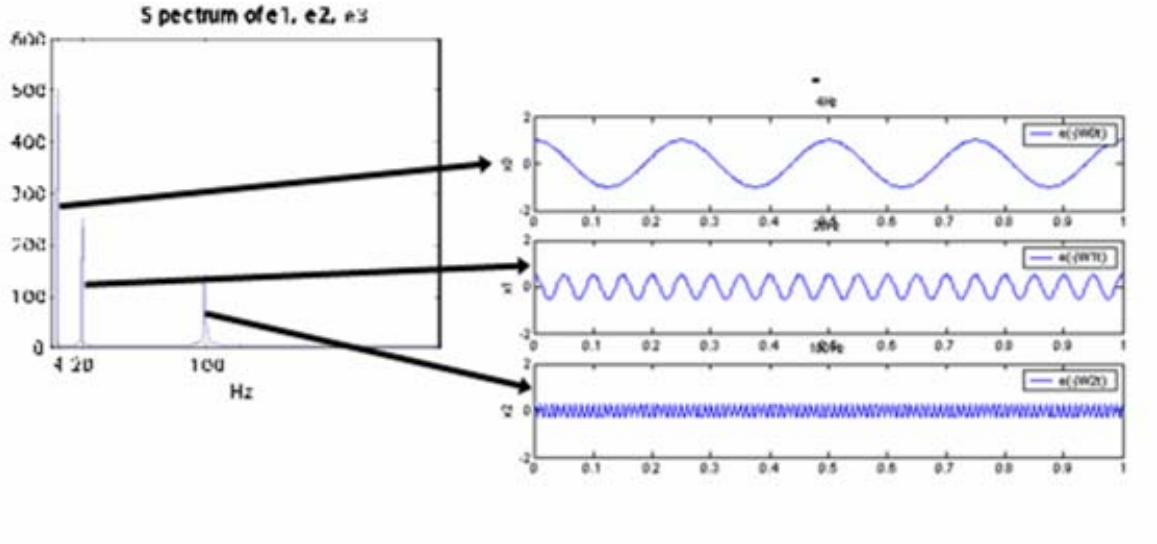


Figure 10. 3-frequency combined signal and their spectrums.

The examples of common signals are shown in following figure.

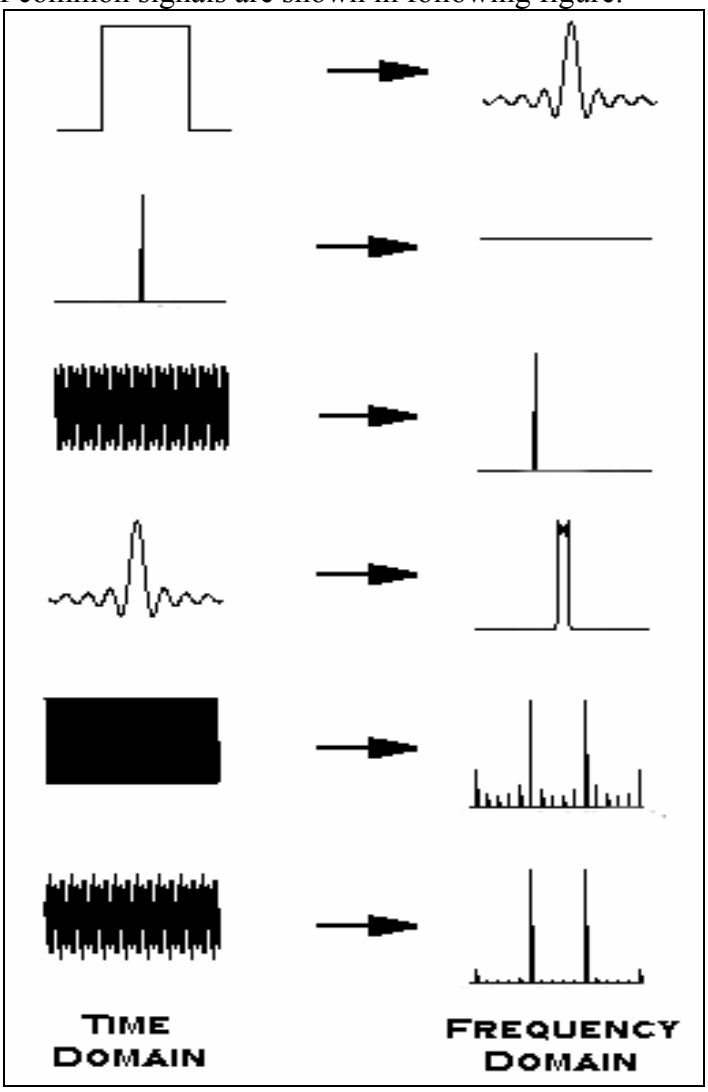


Figure 11. some common signals and their fourier transforms.

For real signal, the equation of Fourier transform is;

$$X(j\omega) = \int_{-\infty}^{\infty} x(t) e^{-j\omega t} dt \qquad \text{(FT 1.)}$$

And inverse Fourier transform is;

$$x(t) = \frac{1}{2\pi} \int_{-\infty}^{\infty} X(j\omega) e^{j\omega t} d\omega \qquad \text{(IFT 1.)}$$

2.3.2 Discrete Fourier Transform

To compute Fourier transform by digital computer, the discrete Fourier transform (DFT) will be used instead of the continuous Fourier transform.

Discrete Fourier Transform:

$$X(\omega) = \sum_{n=0}^{1} x[n] e^{-j\omega n} \qquad \text{(DFT 1.)}$$

Inverse Discrete Fourier Transform:

$$x[n] = \frac{1}{2\pi} \sum_{\omega=0}^{2\pi} X(j\omega) e^{j\omega n} \qquad \text{(IDFT 1.)}$$

n = order of sampling.

For easy to compute, the equation (DFT 1.) and (IDFT 1.) will be changed to:

$$X(r) = \sum_{n=0}^{N-1} x[n] e^{-j(\frac{2\pi}{N} r)n} \qquad \text{(DFT 2.)}$$

$$x[n] = \frac{1}{N} \sum_{r=0}^{N-1} X(r) e^{j(\frac{2\pi}{N} r)n} \qquad \text{(IDFT 2.)}$$

r = order number of frequency resolution (0 to N-1),

N = a number of data per transform.

Or,

$$X(r) = \sum_{n=0}^{N-1} x[n] W_N^{r \cdot n} \qquad \text{(DFT 3.)}$$

$$x[n] = \frac{1}{N} \sum_{r=0}^{N-1} X(r) W_N^{-r \cdot n} \qquad \text{(IDFT 3.)}$$

Where

$$W_N = e^{-j\left(\frac{2\pi}{N}\right)}$$

and $W_N^{r \cdot n} = e^{-j\left(\frac{2\pi}{N}\right) r \cdot n}$ for r = 0 ... N − 1 are called the Nth roots of unity. Below are roots of unity for N = 2, N = 4, and N = 8, graphed in the complex plane.

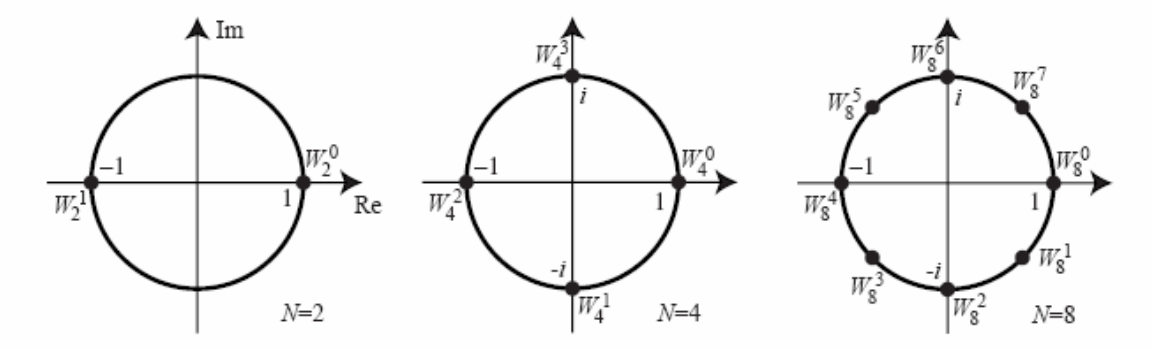


Figure 12. Nth roots of unity for N = 2, N = 4, and N = 8.

Powers of roots of unity are periodic with period N, since the Nth roots of unity are points on the complex unit circle every 2π/N radians apart, and multiplying by WN is equivalent to rotation clockwise by this angle. Multiplication by W_N^N is rotation by 2π radians, that is, no rotation at all. In general, $W_N^k = W_N^{k+jN}$ for all integer j. Thus, when raising W_N to a power, the exponent can be taken modulo N.

Two-point DFT (N=2)

W2 = e−jπ = −1, and

$$\begin{aligned} X(r) &= \sum_{n=0}^{1} (-1)^{r \cdot n} x[n] \\ &= (-1)^{r \cdot 0} x[0] + (-1)^{r \cdot 1} x[1] \\ &= x[0] + (-1)^r x[1] \end{aligned}$$

so

$$X(0) = x[0] + x[1]$$

$$X(1) = x[0] - x[1]$$

Four-point DFT (N=4)

W4 = e−jπ/2 = −j, and

$$X(r) = \sum_{n=0}^{3} (-j)^{r \cdot n} x[n]$$

$$= x[0] + (-j)^r x[1] + (-j)^{r\cdot 2} x[2] + (-j)^{r\cdot 3} x[3]$$
$$= x[0] + (-j)^r x[1] + (-1)^r x[2] + (-j)^r x[3]$$

so

$$\begin{aligned} X(0) &= x[0] + x[1] + x[2] + x[3] \\ X(1) &= x[0] - jx[1] - x[2] + jx[3] \\ X(2) &= x[0] - x[1] + x[2] - x[3] \\ X(3) &= x[0] + jx[1] - x[2] - jx[3] \end{aligned}$$

To compute X(n) quickly, the common sub expressions can be pre-computed as below:

$$\begin{aligned} X(0) &= (x[0] + x[2]) + (x[1] + x[3]) \\ X(1) &= (x[0] - x[2]) - j(x[1] - x[3]) \\ X(2) &= (x[0] + x[2]) - (x[1] + x[3]) \\ X(3) &= (x[0] - x[2]) + j(x[1] - x[3]) \end{aligned}$$

This saves a lot of adds. The process can be expressed as the following diagram for a complex multiply and add:

Figure 13. Butterfly diagram

Then the diagram for 4-point DFT is as below:

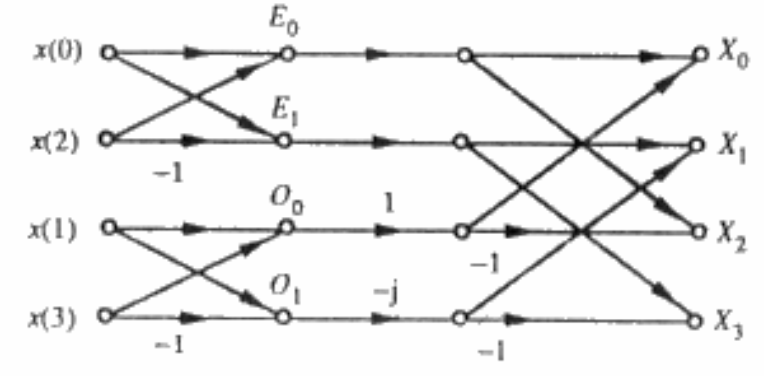


Figure 14. Butterfly diagram for 4-points FFT

If Take the 2-point DFT and 4-point DFT and then generalize them to N = 8, N = 16, and other power-of-two discrete Fourier transforms, will get the Fast Fourier Transform (FFT) Algorithm.

2.3.4 Fast Fourier Transform

The Fast Fourier Transform was firstly described in 1942 by Danielson and Lanczos. They found that DFT use calculation time as 2N2 which can be improve algorithm and speed up FT calculation to N/2. The FFT was developed by many researchers. Until mid-1960s, Cooley W. J. and Tukey J. W. introduced the Fast Fourier Transform, which is commonly used now, that decreases calculation time to Nlog2N. With this speed, the transformation by DFT with 2 weeks long calculation can be finished in 30 seconds by FFT.

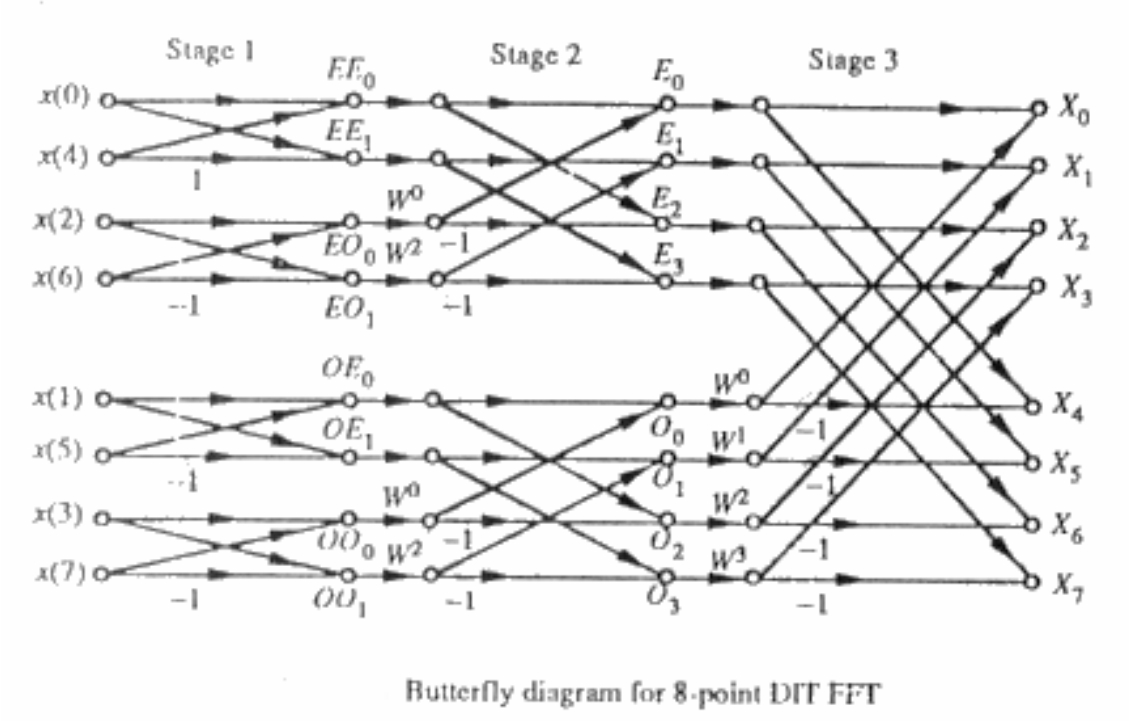


Figure 15. Butterfly diagram for 8-points FFT

From the diagram of 8-point FFT, the number of stage = log2 8 = 3 stage. Each stage, except stage 1st, will have N/2 times multiplication (see Wn) and N times addition. The total computations will equal N log2 N times, or O(N log2 N).

Butterflies and Bit-Reversal

The FFT algorithm decomposes the DFT into log2 N stages, each of which consists of N/2 butterfly computations. Each butterfly takes two complex numbers p and q and computes from them two other numbers, p + αq and p − αq, where α is a complex number. Below is a diagram of a butterfly operation.

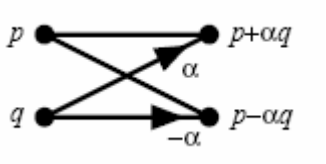


Figure 16. Butterfly diagram

In the diagram of the 8-point FFT above, note that the inputs aren't in normal order: a0, a1, a2, a3, a4, a5, a6, a7, they're in the bizarre order: a0, a4, a2, a6, a1, a5, a3, a7. Below is a table of j and the index of the jth input sample, nj:

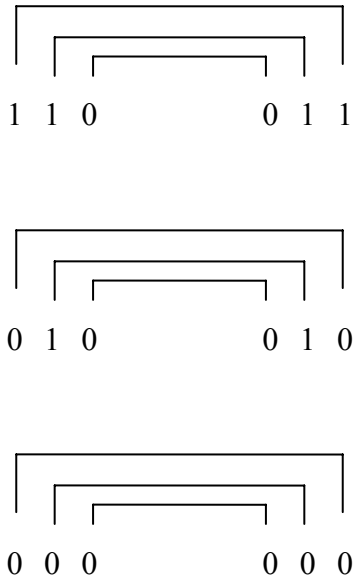
Table 3. table of j and the index of the jth input sample, nj

j	0	1	2	3	4	5	6	7
nj	0	4	2	6	1	5	3	7
j base 2	000	001	010	011	100	101	110	111
nj base 2	000	100	010	110	001	101	011	111

The pattern is obvious if j and nj are written in binary (last two rows of the table). Observe that each nj is the bit-reversal of j. The sequence is also related to breadth-first traversal of a binary tree.

It turns out that this FFT algorithm is simplest if the input array is rearranged to be in bit-reversed order. The re-ordering can be done in one pass through the array:

$$\text{position } 6 \rightarrow 110 \rightarrow 011 \rightarrow 3$$
$$\text{position } 2 \rightarrow 010 \rightarrow 010 \rightarrow 2$$
$$\text{position } 0 \rightarrow 000 \rightarrow 000 \rightarrow 0$$



The below diagrammed algorithm for the 8-point FFT is easily generalized to any power of two.

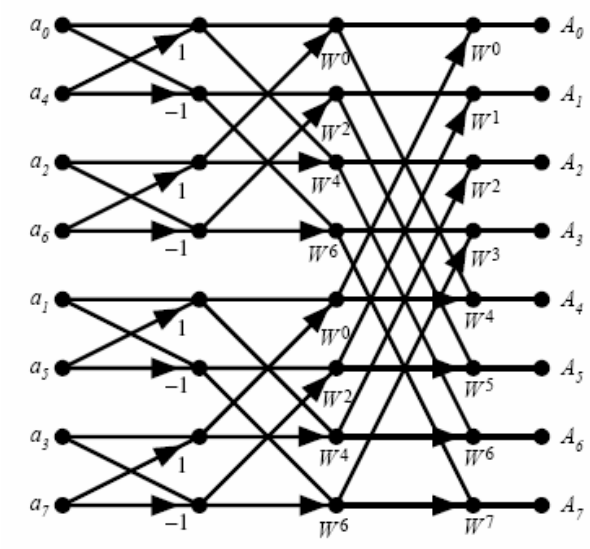


Figure 17. Diagram of 8-point FFT with Wn description

The input array is bit-reversed, and the butterfly coefficients can be seen to have exponents in arithmetic sequence modulo N. For example, for N = 8, the butterfly coefficients on the last stage in the diagram are W0, W1, W2, W3, W4, W5, W6, W7. That is, powers of W in sequence. The coefficients in the previous stage have exponents 0,2,4,6,0,2,4,6, which is equivalent to the sequence 0,2,4,6,8,10,12,14 modulo 8. And the exponents in the first stage are 1,-1,1,-1,1,-1,1,-1, which is equivalent to W raised to the powers 0,4,0,4,0,4,0,4, and this is equivalent to the exponent sequence 0,4,8,12,16,20,24,28 when taken modulo 8. The width of the butterflies (the height of the ”X’s” in the diagram) can be seen to be 1, 2, 4, ... in successive stages, and the butterflies are seen to be isolated in the first stage (groups of 1), then clustered into overlapping groups of 2 in the second stage, groups of 4 in the 3rd stage, etc. The generalization to other powers of two should be evident from the diagrams for N = 4and N = 8. (10), (11)

2.3.5 Short time fourier transform (Gabor Transform)

Anyway, there is a well-known error from Fourier transform. FT gives a good frequency resolution, but it don’t tell when those frequency happen. If x(t),for example, are data of EEG, which sampled in a whole day. The FT of x(t) will not show exact time, which abnormal EEG appear. To show time information, the window function will be applied onto data x(t). The window will separate data to many periods. Then we use FT to each period of x(t).

The frequency spectrum from window function have noise or ringing effect. To decrease noise, the Gaussian window function was introduced to use instead of normal window. This method is named Short Time Fourier Transform (STFT) or Gabor Transform. STFT equation is;

$$STFT_{X(\omega)} = \int_{t} [x(t) \cdot \omega^{*}(t - t')] \cdot e^{-j2\pi ft} dt$$

And the figure, below, show the signal, which be multiplied with Gaussian window.

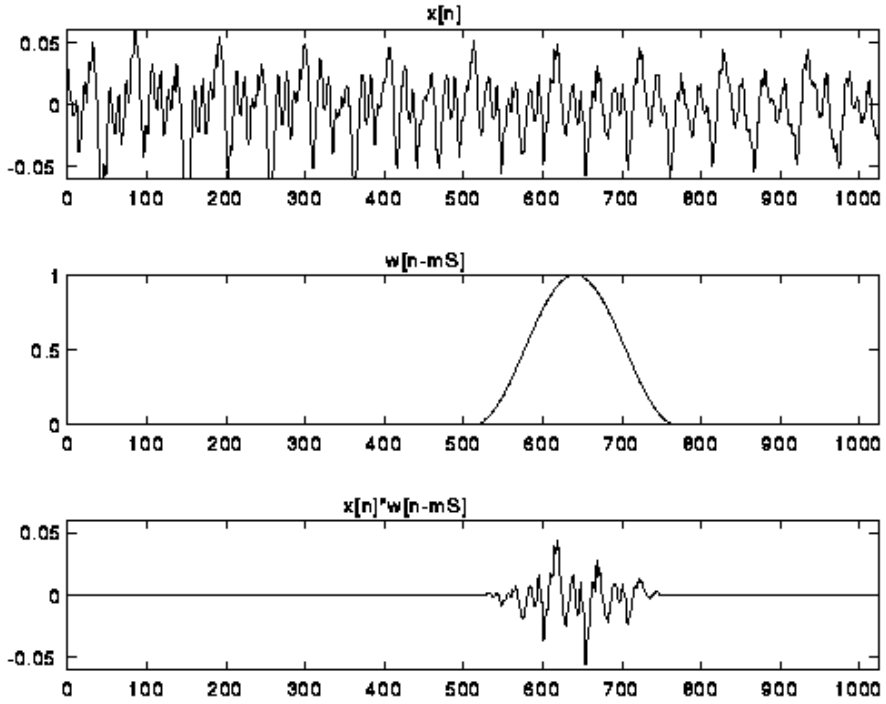


Figure 18. An example of how signal is windowed. (12)

STFT still have problem in frequency resolution and time resolution. If high frequency resolution is required, the wide window will be used. But with wide window time resolution will lost its accuracy. In another way, if high accuracy in time is required, the narrow window will be used. But, again, the narrow window will decrease frequency resolution. This problem is known as the Heisenberg Uncertainly Principle, which states that it is impossible to know the exact frequency and the exact time of occurrence of this frequency in a signal. (13)

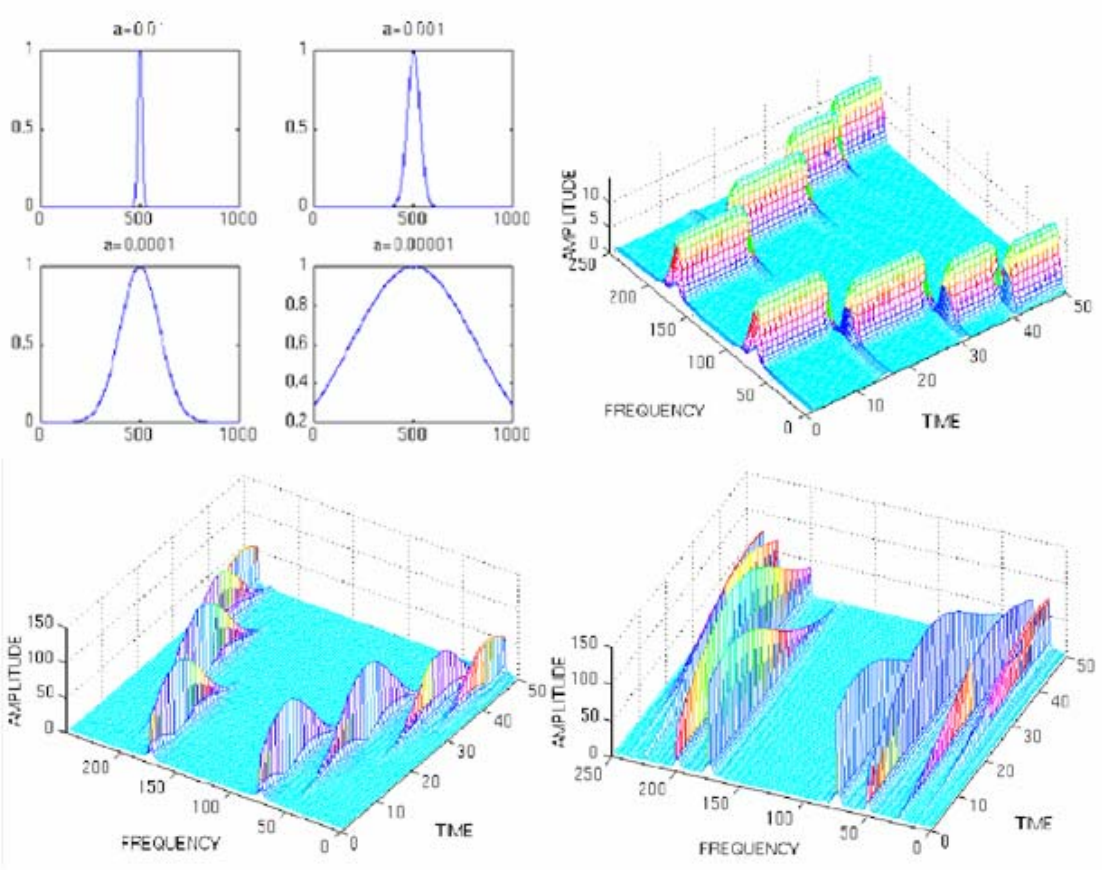


Figure 19. problems of time-frequency resolution of STFT. (a) window function (b-d) STFT with varies window functions from (a) (14)

2.3.6 Wavelet Transform

The concept of wavelets in its present theoretical form was first proposed by Jean Morlet in 1984 and the team at the Marseille Theoretical Physics Center working under Alex Grossmann in France. (15)

At this time the well-known Fourier Transform is known that it give an error result. Because Fourier Transform is based on stationary signal while the signal in natural is un-stationary signal. The result is Fourier Transform do not tell the exact time that spectrum existed. But it shows all spectrums those existed in whole signal ($-\infty \leq t \leq \infty$). To get spectrums in each period of signal, we use window function to separate periods of transform, this method are known as STFT. To improve a better time resolution, we choose a small window to transform. Unavoidable, it will decrease the frequency resolution. And if we select a good frequency resolution, we must use a

larger window, then we will lose a time resolution. This phenomenon is described by the Heisenberg's Uncertainly Principle. (13), (16), (17)

Wavelet Transform is probably the most recent solution to overcome the short comings of the Fourier Transform. Wavelet Transform use variable-sized window functions base on signal. One wave of low frequency signal appear longer period while one wave of high frequency signal appear in shorter period. Wavelet transform allows the using of vary scales of windows; long region window to transform low frequency, and shorter region window to transform in high frequency. (14)

2.3.6.1 Continuous Wavelet Transform

Wavelet transform has a variable-sized window, which has a same shape according to a unique shape called mother wavelet φ(t).

The set of window function those created from one mother wavelet is called Wavelet Family φa,b. The relation of wavelet family and mother wavelet is:

$$\varphi_{a,b}(t) = |a|^{-1/2} \varphi\left(\frac{t-b}{a}\right)$$

'a' is the scale(or size) and b is translation(shifting) parameters. As parameter a increases, the wavelet become more narrow and by varying parameter b, the wavelet is displaced in time. Thus, the wavelet family gives a unique pattern and repeat at variable scale and variable localization in time

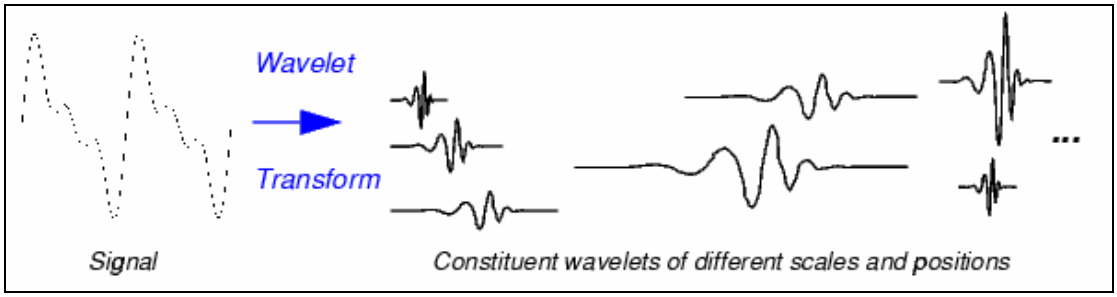


Figure 20. Wavelet at different scale and translation. (15)

wavelet transform is:

$$CWT_{\varphi \cdot x}(a,\ b) = \psi_{\varphi \cdot x}(a,\ b) = |a|^{-1/2} \int_{-\infty}^{\infty} x(t)\varphi^{*}\left(\frac{t-b}{a}\right)dt$$

where * denotes complex conjugate. This equation is called Continuous Wavelet Transform.

2.3.6.2 Discrete Wavelet Transform

Discrete Wavelet is calculated by discrete scaling(a) and discrete shifting(b) of wavelet family. One choice to select how to scaling and shifting is choosing the set of parameters aj=2j, bj,k = 2jk with j,k ∈ Z. Replacing in equation (mother wavelet function), the new discrete wavelet family is:

$$\varphi_{j,k} = 2^{-j/c}\varphi\left(2^{-j}t - k\right)$$

This equation is called Dyadic Wavelet Transform.

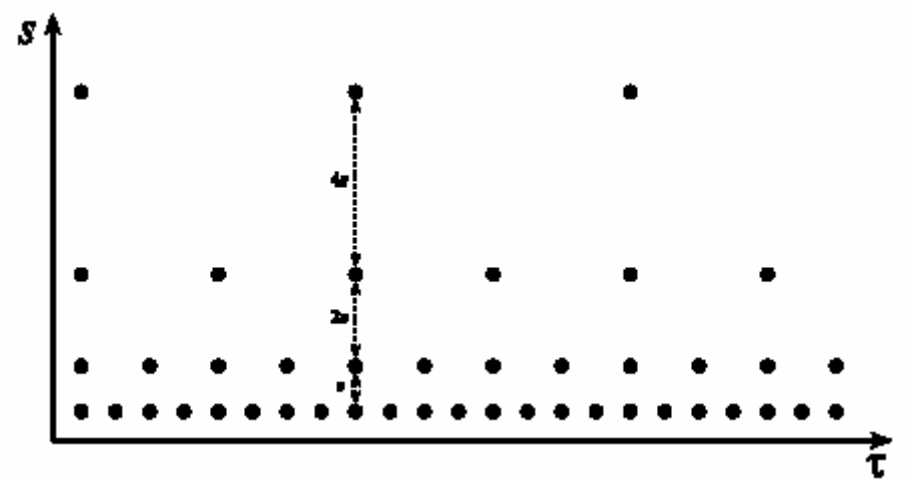


Figure 21. Dyadic grid (13)

The wavelet function can be calculated by an efficient way that introduced in 1989 by S. Mallat (18). This method is called two channel subband coding. This method constructs two filters along dyadic grid, Low-Pass filter and High-Pass fileter.

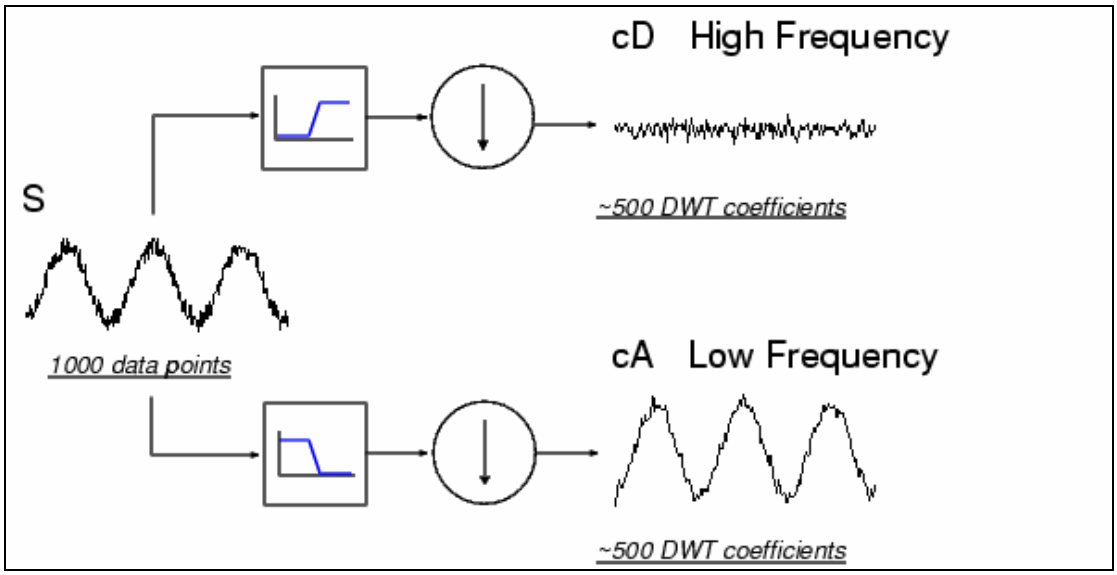


Figure 22. Wavelet analysis filter trees. (15)

For example,

Low-pass filter is averaging filter,

Ave = (x1+x0)/2 (Haar 1)

High-pass filter is differential filter,

Dif = (x1-x0)/2 (Haar 2)

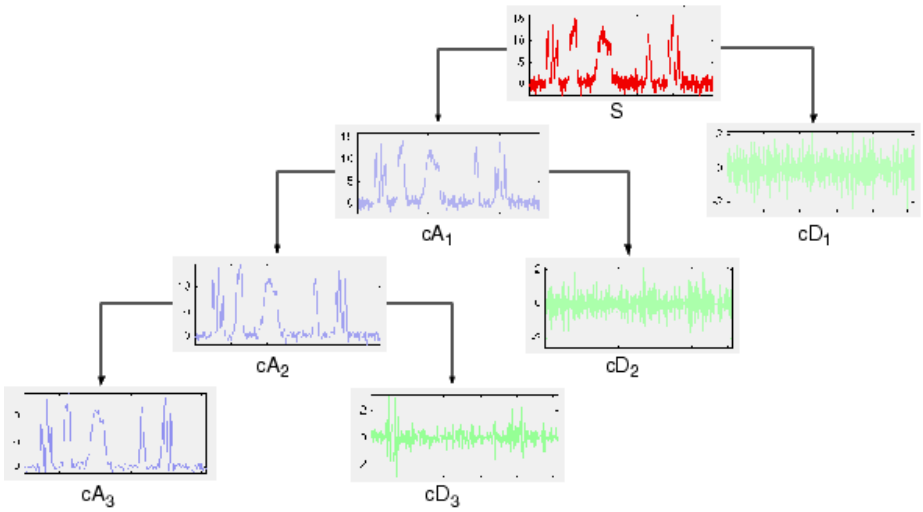


Figure 23. Wavelet decomposition filters trees.

The most important properties of wavelet transform is that the data can be completely reconstructed. Figure below present the concept of complete decomposition and reconstruction.

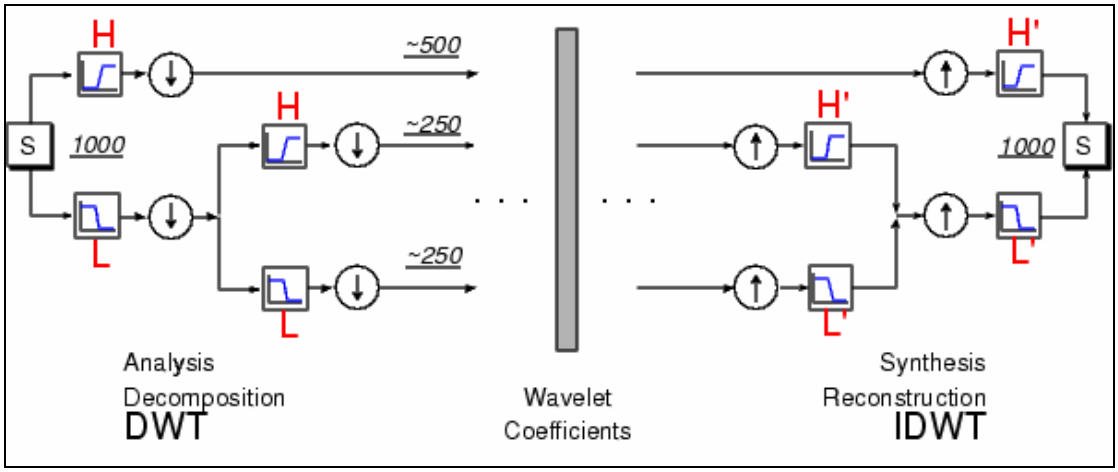


Figure 24. Wavelet decomposition and reconstruction filter trees. (15)

Wavelet transform is proved to be a very useful tool for analyzing brain. Two advantages of Wavelet Transform over Fourier based methods. First, Wavelet Transform lacks of the requirement of stationarity, this being crucial for avoiding spurious results when analyzing brain signals which already known to be highly non-stationary. Second, owing to the varying window size of the Wavelet Transform, a better time-frequency resolution can be achieved when the signal has patterns involving different scales. (9)

2.4 Review of Related Works

2.4.1 Simple Interpolation Methods in 3D EEG Brain Mapping

From K. H. Kim, J. H. Kwon, D. H. Lee, S. I. Kim, "The 3D Brain Topography Based on PC" , Proc. Ann. Conf. IEEE/EMBS 19,1997,Oct. 30 – Nov. 2, the researchers use 3D barycentric algorithm to interpolate the EEG data. The results are mapped on the semi-sphere graphic model.

$$v_e = \frac{\left(\sum_{i=1}^{n} v_i \cdot \frac{1}{d_i m} \right)}{\left(\sum_{i=1}^{n} \frac{1}{d_i m} \right)}$$

Ve = the interpolation value

Vi = the measures value at the i_{th} point of measure

di = the Euclidean distance of the point M(x,y,z) (not joined with a point of measure) and the i_{th} point of measure

$$= \sqrt{(x - xe_i)^2 + (y - ye_i)^2 + (z - ze_i)^2}$$

n = the number of electron

m = the order of interpolation

X, Y, Z = the arbitrary location on semi-sphere

Xei, Yei, Zei = the location of electron.

Figure 18-20 respectively shows 16 points of measurement, the 16-chennel recording of spikes and the typical results.

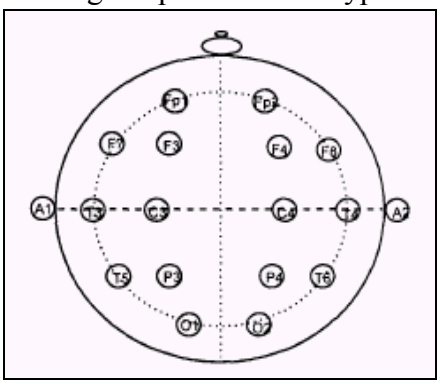


Figure 25.
Electrode Array for 16 Channels

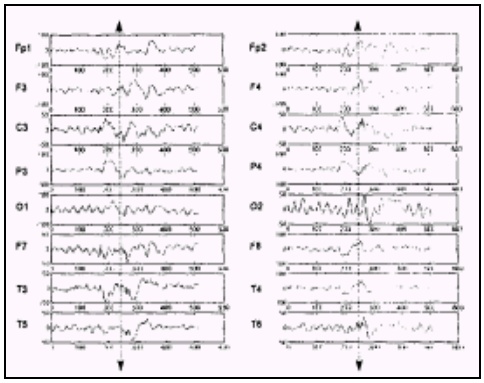
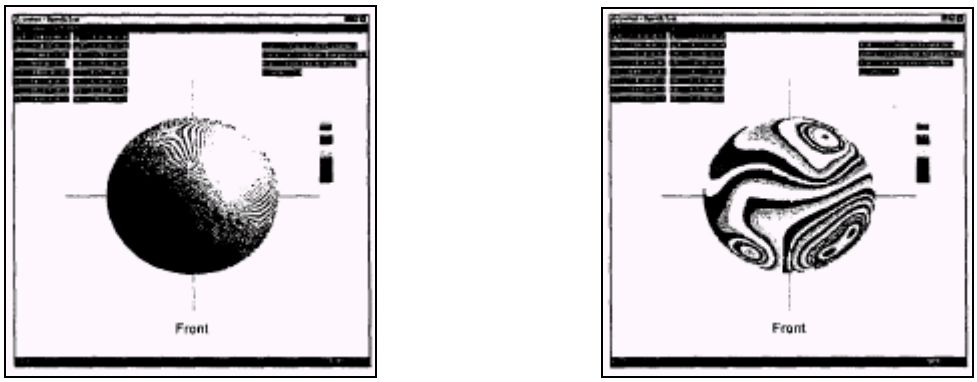


Figure 26. Epileptic Interictal Spike Recorded from a Patient (Arrow is the point where is interpolated)



(a) (b)

Figure 27. Result (a) a patient having spikes. (b) a normal patient

2.4.2 Comparisons of Different Interpolation Methods

Statistic comparisons of different map interpolation techniques have been performed by Soong et al., "Systematic comparisons of interpolation techniques in topographic brain mapping". Electroencephalography and Clinical Neurophysiology, vol. 87, pp.185-195, (1993); For epileptiform spikes recorded using 31 electrodes, they found that the 19 electrodes used in routine 10-20 configurations interpolated statistically more accurately with the original 31-electrode data using spline interpolation than with the nearest neighbor rule interpolation methods.

Souflet et al., Electroencephalography and Clinical Neurophysiology (1991),evaluated 7 different interpolation methods on normal 64-channel EEG data. They interpolated the data from 28 standard 10-20 electrodes and compared it to the original 64-electrode data. The error of the localization of the maximum, the overvoltage of the maximum and the RMS (root mean square) error were collectively minimized using spline interpolation techniques.

These studies suggest that spline interpolation is the best algorithm for voltage mapping of spike potential fields.

2.4.3 Filtering in 3D EEG Brain Mapping

Pei-Chen Lo, "Three-Dimensional Filtering Approach to Brain Potential Mapping" IEEE Transactions on Biomedical Engineering Vol. 46, NO. 5, MAY 1999, presents an alternative approach to reconstruction of the EEG topographical mapping on the scalp surface.

In this research, according to visual inspection, the potential mapping interpolated by the 3-D filtering method has a quality comparable to that obtained by the 4NN and spherical spline methods. Based on the quantitative error criteria, the performance of the 3-D filtering method compares well with the commonly used 4NN method. In comparison with the spherical spline method, the potential mapping interpolated by the 3-D filtering method deviates more from the true mapping due to the alteration of the true potential values, by the filtering process, at the recording sites. See Tables C.1 and C.2 for more details.

Table 4. Computation Time (in S) Required by Different Methods

Computation Time (in S) Required by Different Methods			
	19-eletrode array	33-eletrode array	45-eletrode array
3D Filtering Method	0.72	0.71	0.72
4NN Method	0.36	0.47	0.60
Spherical Splines Method (m=3)	1.8	3.0	4.2

Table 5. Performance Comparison

Eccentricity of dipoles	Electrode array	3D filtering	4NN	Spherical splines (m=3)
0<=eccentricity<=0.3	19	0.07(0.08π)	0.05	0.01
	33	0.07(0.12π)	0.05	<0.01
	45	0.07(0.13π)	0.04	<0.01
0.3<=eccentricity<=0.6	19	0.15(0.10π)	0.16	0.10
	33	0.12(0.12π)	0.13	0.05
	45	0.11(0.12π)	0.10	0.03
0.6<=eccentricity<=0.8	19	0.38(0.11π)	0.40	0.35
	33	0.31(0.13π)	0.31	0.25
	45	0.28(0.14π)	0.25	0.17
0<=eccentricity<=0.8	19	0.20	0.20	0.15
	33	0.17	0.16	0.10
	45	0.15	0.13	0.07

2.4.4 Wavelet packet analysis in EEG

M. Shen, L. Sun and F. H. Y. Chan, "Method for extracting time-varying rhythms of electroencephalography via wavelet packet analysis", IEEE Proc.-Sci. Meas. Technol., Vol148, No. 1, Jan. 2001, illustrate how wavelet packet analysis can be applied to time-varying EEG rhythm decomposition with high time-frequency location resolution and to forming the dynamic EEG rhythm topography. See more of typical EEG signals and rhythms in Figures 21 and 22.

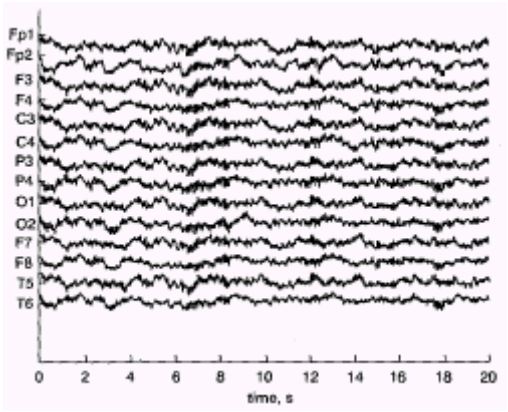


Figure 28. 14-channel EEG signals of 20 sec from normal subject at rest with eyes closed.

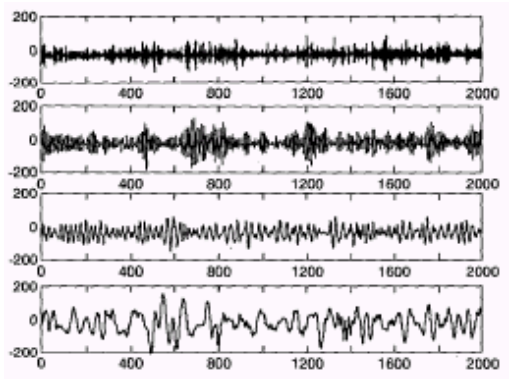


Figure 29. Time-varying brain rhythms of C3 channel EEG record in Fig. 28.

2.4.5 Comparison of EEG 3D brain mapping Vs. Human Analysis

Samuel Kosezr, Solomon L. Moshe, Alan D. Legatt, Shlomo Shinnar, Eli S. Goldensohn, "Surface mapping of spike potential fields: experienced EEGers vs. computerized analysis", Electroencephalography and Clinical Neurophysiology 98 (1996) 199-205, present the spherical mapping technique used for localization of epileptiform spikes can compare favorably with traditional clinical EEG interpretation.

CHAPTER III
MATERIAL AND METHODS

3.1 Material

Data

Source of Data	From an EEG database of NEURO-BEHAVIOURAL BIOLOGY CENTER.
Data Acquisition Machine	Biologic Brain Atlas Version 2.34
Data File Format	Continuous EEG (Exxxxxxx.dat)
EEG Subject type	Unspecific Syndrome Unspecific Sex Unspecific Age
EEG data specific	21 electrodes (10-20 systems) Sampling Rate 128 Hz 8 bits

Research Tools

PC

- AMD Athlon 1700+
- DDR-RAM 256 MBs
- Harddisk 40 GBs
- Riva TNT2MX 32 MBs

Software

- Microsoft WindowsXP
- Visual C++ and Visual C#.Net
- Microsoft DirectX9 SDK

3.2 Methodology

3.2.1 Research Planning

The subject of thesis is setup by guiding from of NEURO-BEHAVIOURAL BIOLOGY CENTER. The researching steps are related with chapters in this thesis.

Firstly, the early scope of research is on “3D visualized brain mapping”. This scope is based on pure 3d programming. So, it is necessary to include some medical diagnosis function into the research. The new scope is “3D visualized brain mapping with General epilepsy spike detection” which are satisfied in the first state.

But after analyzing the obtained data, the researcher found an unfixable error in the data. The data of general epilepsy (which are known that it must have 3 Hz spike distribution) cannot be used in the research. Because the data amplitudes are too high then the peak of data are clipped off.

So, the scope of research is necessary to be changed. The new scope is “3D visualized Brain Mapping and Spike Detection with Wavelet Analysis”. This new scope is more useful than the old scope. Because the output of spike detection function can be applied to many research in EEG field. And it also convince EEGers to ensure their analysis and diagnosis results. (19)

3.2.2 Software Design & Development

In the development phase, each parts of software are developed separately. The purpose is to ensure that each process can work satisfyingly, without internal errors. The first part is a Brain Atlas file-loader, for reading EEG file generated from EEG machine which consists of vary fields of information, for samples, patient information, file information, measure and experiment parameters. The second part is software for various transformation experiments which mainly transforms EEG data from time domain to frequency domain and/or separates for any sub frequency bands such as delta, theta, alpha, and beta. The third part is 2D and 3D topographic mapping. The final part is spike detection. All part must be satisfying accepted before implemented together.

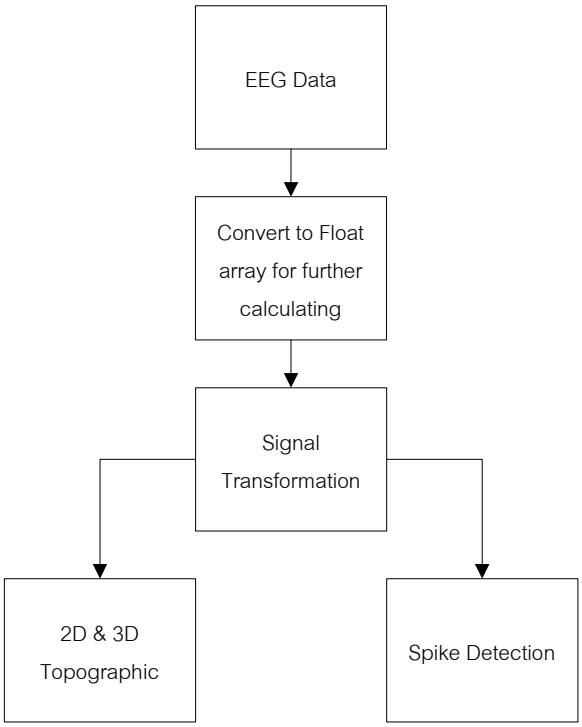


Figure 30. Flowchart of program flow

After all testing parts are satisfied accepted; all parts will be implemented into one final application.

3.2.2.1 Part 1: File Opener

The first program prepare data for the next other programs. The data are obtained from Bio-Logic Brain Atlas version 2.345 (BA version 2.345) at NEURO BEHAVIOURAL BIOLOGY CENTER.

BA 2.345 machine can give data in 3 formats EEG, EP, and FFT. This research will use only EEG type. The EEG filename are put 'E' as prefix (Exxxxxxxx.dat) by machine default. This file format has 2176 byte-long header. And the raw-record data are start at address 2176 of file. Other detail of file structure is in appendix A.

The ready-to-use data can be calculates from raw-record data with some calibrated values of machine system by this equation:

uv per bit = (200.0 / Calib AD Width[21]) * (20000 / Gain[21])

DC Offset Voltage[] = (Calib DC Value[21] - 128) * (Gain[21] / 300000) * uv per bit

Data Value[21][] = (AD value - 128) * uv per bit) + DC Offset Voltage[]

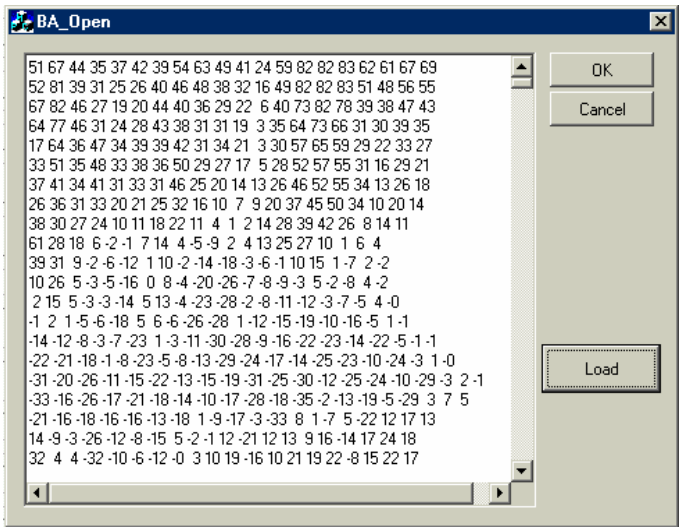


Figure 31. Biologic File Open Dialog.

The program translate data file from BA version 2.345 and then export to array as:

Float[21][]={...uV}; //float [electrode number][sampling number]

3.2.2.2 Part 2: Data Transformation

This program transforms the EEG Data to display each frequency band characterizing EEG activity.

This program provide 4 functions for user

- Correlation Mapping
- Gabor Transform (STFT)
- Haar wavelet transform
- B-Spline wavelet Transform

Correlation mapping method will map the sinusoidal signal along whole EEG data, from start to end. The result of this method will show the correlation ratio between EEG signal and a period of sinusoidal signal model at each sampling point. To screening the significant level of the correlation rate, the threshold value can be manually adjusted by user through provided scrolling bar. The second method, Gabor transform, is the conventional method to study the signal behavior. This method has been proved to be one of the most important weapons in the world of digital signal analysis. The next one, Haar wavelet Transform, is the simplest wavelet transform which be proved that data can be perfect reconstruction. This method was widly use in

digital signal processing since the mother wavelet is digital-liked square wave. The last method, B-Spline wavelet transform, is the wavelet which be proved that it fit for bio-signal analysis. And this research will provide a graphical result for showing how the different these methods are.

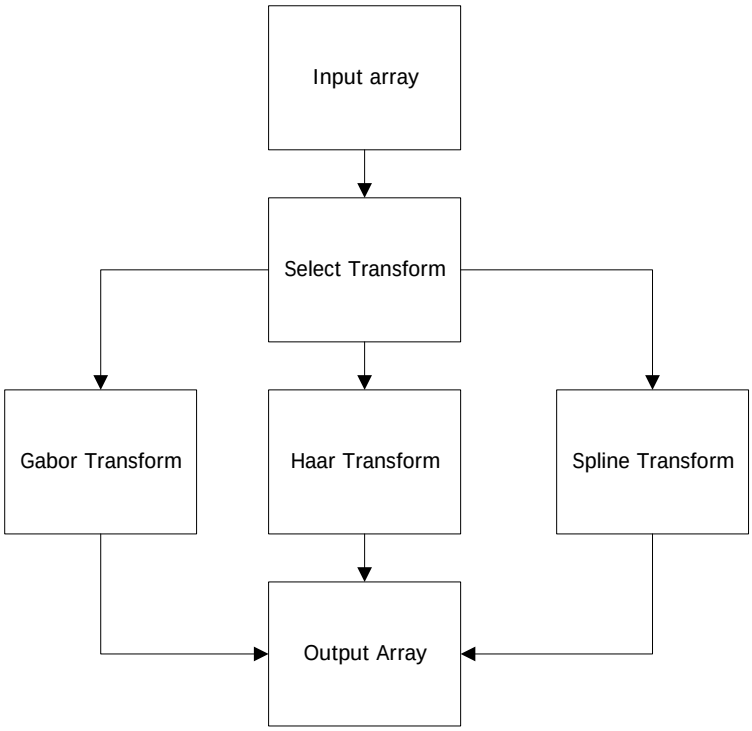


Figure 12. Flowchart of program part 2

The output of selected signal transformation will be exported to the array of output value. The output can be applied for further frequency inspection or can be grouped to Delta, Theta, Alpha, and Beta Band.

3.2.2.3 Part 3: 3D Topographic

This program use DirectX9 API to show EEG Data or transformed data in 3-dimension. The program read the array of float data[21][] and convert to an array of color_data[21]. Then assign color values from the array of color_data[21] to electrodes as show in table 3.

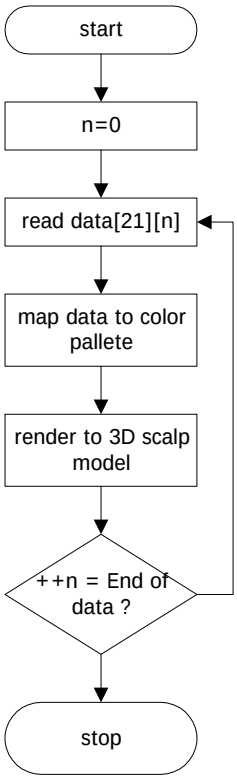


Figure 33. Flowchart of program part 3

Table 6. position of data array[21] (data[20] is assigned to a reference electrode.)

	Color[0]=>Fp1		Color[1]=>Fp2	
Color[2]=>F7	Color[3]=>F3	Color[4]=>Fz	Color[5]=>F4	Color[6]=>F8
Color[7]=>T3	Color[8]=>C3	Color[9]=>Cz	Color[10]=>C4	Color[11]=>T4
Color[12]=>T5	Color[13]=>P3	Color[14]=>Pz	Color[15]=>P4	Color[16]=>T6
	Color[17]=>O1	Color[19]=>Oz	Color[18]=>O2	

The data of EEG will be convert to color of their vertex by mapping to a color Table. Convert EEG to color:

```
D3Dcolor mapColorfromEEGValue(float datum)
{
        return ColorTable[(int)datum*255/maxdatumvalue];
}
```

Now, all electrodes have their color, then map the color to prepared electrode position (X,Y,Z) in 3D world.

In the first testing program, the area between vertexes will be shaded by interpolated color. This program use Gouraud shading which can be calculated by many 3D display adapters on current market which will highly accelerate the processing time.

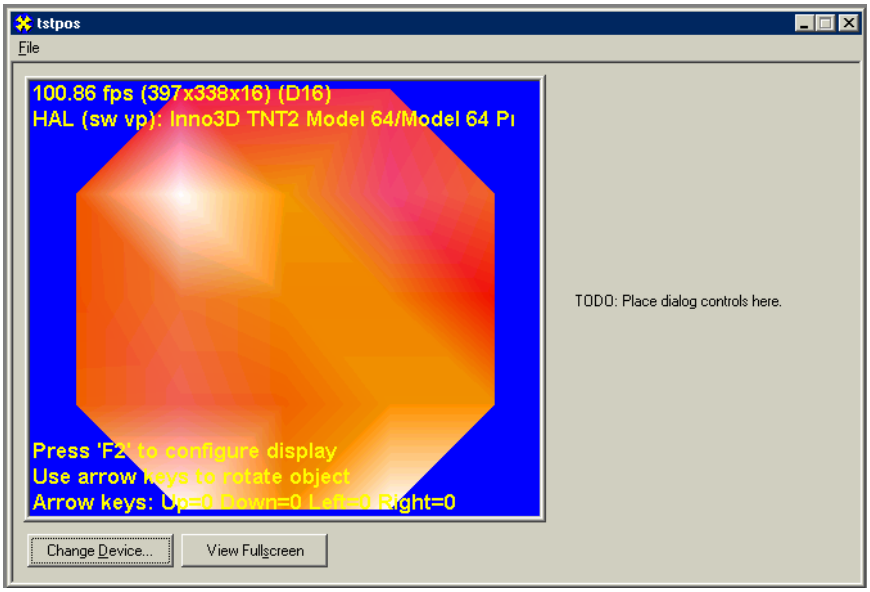


Figure 34. First developing program for 3D EEG Displaying

In the second testing program, the 3D head model was used. And the EEG signal was map on to this head model by DirectX point light source.

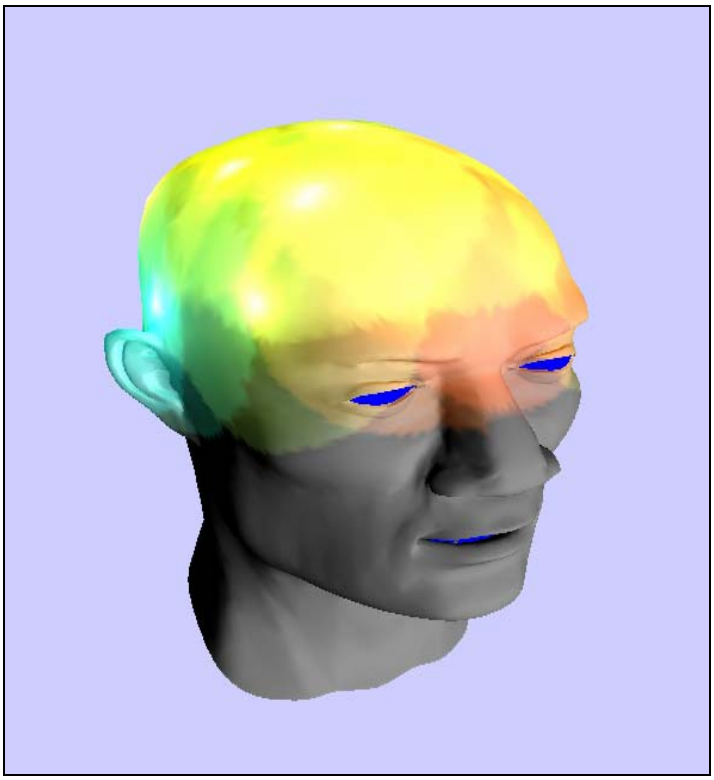


Figure 35. Later developing program for 3D EEG Displaying

3.2.2.4 Part 4: Spike detection

This part of program is the spike detection. The properties of spike can be selected by the selection of 2 factors; the first is an amplitude value and the second is width of signal wave (in raw EEG data) or frequency band (in Gabor) or scaling size (in wavelet).

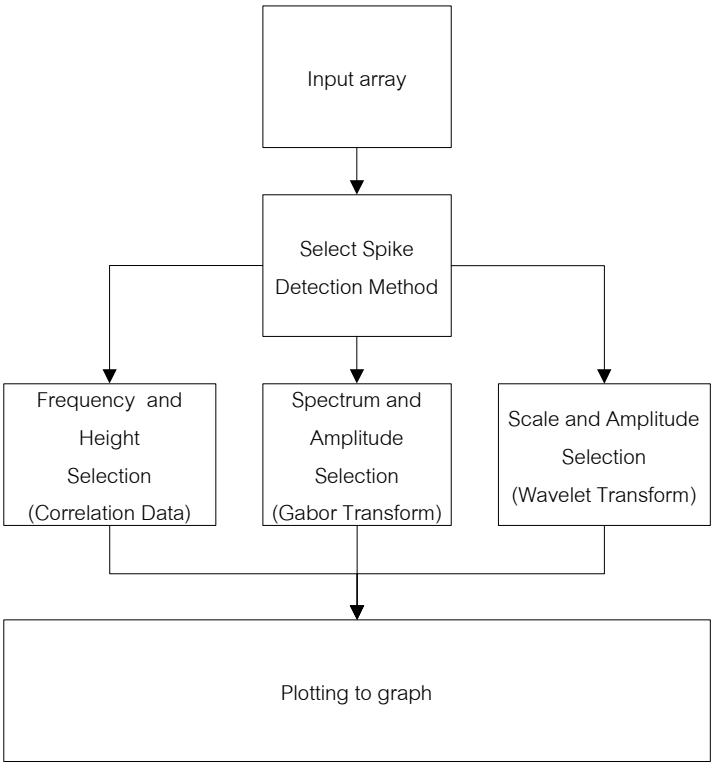


Figure 36. Flowchart of part 4

The target of this part is to provide a plotting function of raw EEG signal with the Spike detected sign.

3.3 Signal Analysis and Transformation Algorithms

3.3.1 Cross Correlation

The cross-correlation function is a measure of the similarities or shared properties between two signals. Given two N-length sequences, x(k) and y(k), with zero means, an estimate of the cross-correlation is given by

$$\rho_{xy}(n) = \frac{r_{xy}(n)}{\left[r_{xx}(0) r_{yy}(0)\right]^{\frac{1}{2}}}; n = 0, \pm 1, \pm 2, \ldots$$

Where rxy (n) is an estimate of the cross-covariance and defined as

$$r_{xy}(n) = \begin{cases} \frac{1}{N} \sum_{k=0}^{N-n-1} x(k) y(k+n); n = 0,1,2,\ldots \\ \frac{1}{N} \sum_{k=0}^{N+n-1} x(k-n) y(k); n = 0,-1,-2,\ldots \end{cases}$$

$$r_{xx}(0) = \frac{1}{N}\sum_{k=0}^{N-1}[x(k)]^2 \quad , \quad r_{yy}(0) = \frac{1}{N}\sum_{k=0}^{N-1}[y(k)]^2$$

EEG data will be assigned as ryy. And the signal model which was created for finding the similarity will be assigned as rxx. To find the correlation with a sinusoidal wave, the signal model is created by simply cosine function.

```
While(k = 0 to N)   //N = Sampling Rate / frequency of interest
{
        CosWave(k) = cos(k*2*PI/(N-1));
        rxx = rxx + CosWave(k)^2;
}
rxx = rxx / N;
```

Then cutting part from sequence of EEG data, and finding correlation with sinusoidal signal model, was defined by;

```
While(n) // n = Length of input data, for each electrode
{
        while( k = 0 to N ) //N = Sampling Rate / frequency of interest
        {
                ryy = ryy + data[n+k]^2;
                rxy(n) = rxy(n) + ( CosWave [k] * data[k+n]);
        }
        ryy = ryy / N;
        rxy(n) = rxy(n) / N;
        pxy(n) = rxy(n) / Sqrt(rxx * ryy);
}
```

Beside a single cosine single model, the signal model can be changed to other shapes by adjustment in rxx loop, for sample, wave group or burst correlation.

```
While(k = 0 to N)   //N = Sampling Rate / frequency of interest
{
        x= k -(N/2) / (N-1); // generate -0.5 to 0.5
                                  x^2
        Burst(k) = exp( -  ------  * Sin(2¶x * NumberOfWave) ) / N;
                                   2
```

```
            rxx = rxx + (Burst(k)^2);
        }
        rxx = rxx / N;
```

3.3.2 Fast Fourier Transform and Short time fourier transform

This section display FFT and STFT (Gabor Transform) as shown in flowchart below.

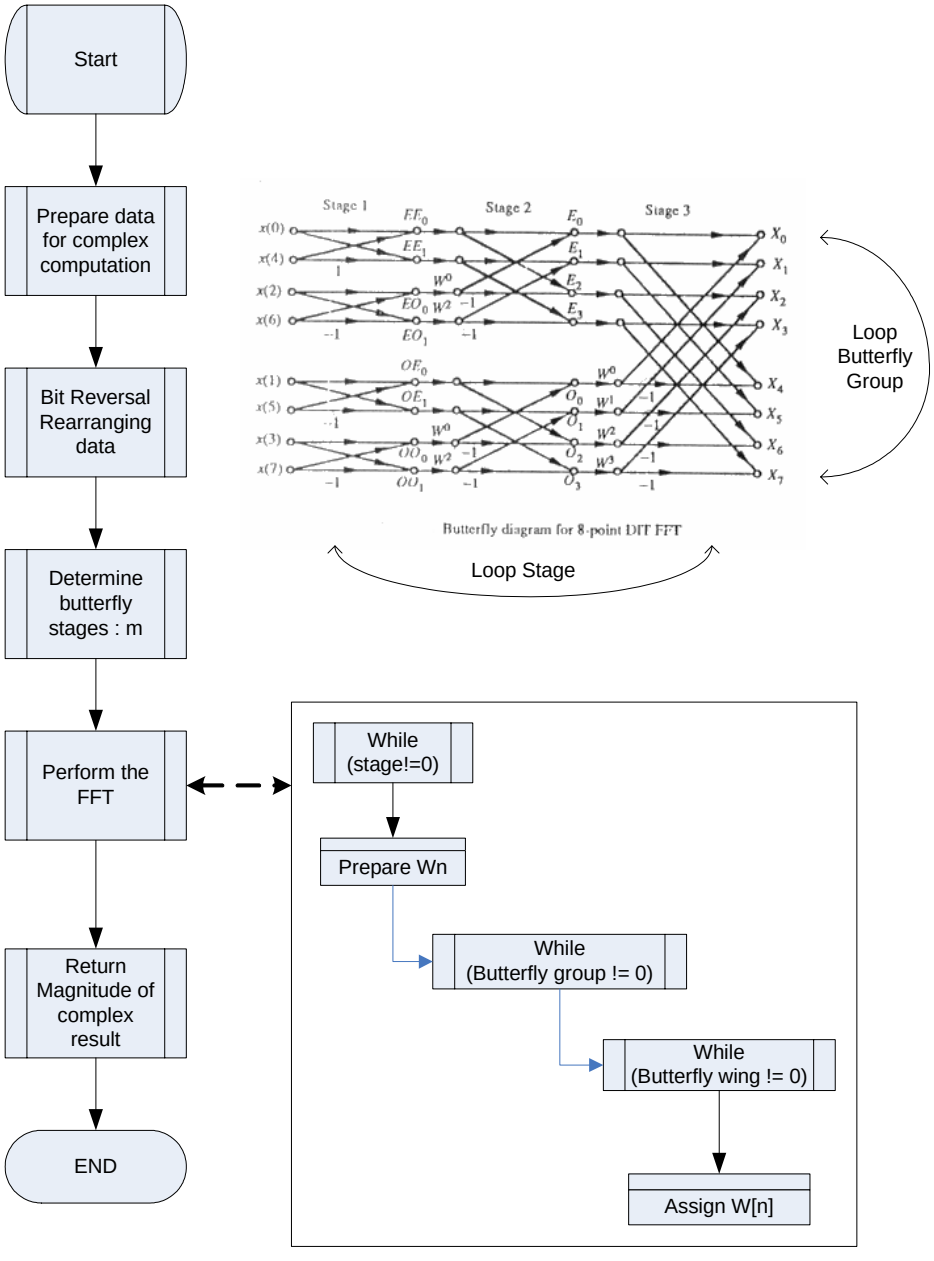


Figure 37. Flowchart of FFT

3.3.2.1 Prepare data for Complex Computation

```
for(int i=1 ; i<=SamplingRate ; i++)
{
        x[i,0] = data[second+i-1];      //real value
        x[i,1] = 0.0f;                  //imagine value
}
```

3.3.2.2 Bit Reversal-Rearranging data

```
//Bit Reversal

int NumPoint = (x.Length-1)/2;
int halfindex=1;
int reversePoint;
float tmp_imag,tmp_real;

for(int index=1 ; index < NumPoint ; index++)
{
        if(index<halfindex)//just swap x[halfindex] with x[index]
        {
                tmp_real = x[halfindex,0];
                tmp_imag = x[halfindex,1];

                x[halfindex,0] = x[index,0];
                x[halfindex,1] = x[index,1];

                x[index,0] = tmp_real;
                x[index,1] = tmp_imag;
        }
        reversePoint=NumPoint/2;
        while(reversePoint<halfindex)
        {
```

```
                halfindex-=reversePoint;
                reversePoint/=2;
        }
        halfindex+=reversePoint;
}
```

3.3.2.3 Calculate number of butterfly stages: m = log2(NumPoint)

```
int m=(int)Math.Log(NumPoint,2);
```

3.3.2.4 Performing the FFT

The codes below consist of 4 sub parts, which are;

- loop for each state
- prepare W_n on the current state
- sub loop for each butterfly group in current state
- sub-sub loop for each butterfly in current group

```
int     index_a,        // Pointer-member1 of butterfly diagram
        index_b,        // Pointer-member2 of butterfly diagram
        BTFly_size,     // size of butterfly diagram which will be
                        //              = 2 : stage 1
                        //              = 4 : stage 2
                        //              = 8 : stage 3
        BTFly_step_to_pair,// length between index_a and index_b
                                //              = 1 : BTF size 2 : stage 1
                                //              = 2 : BTF size 4 : stage 2
                                //              = 4 : BTF size 8 : stage 3
        BTFlys_group_pointer; // point to each butterfly diagram
                                // there will be a small loop
                                // for sub-diagram in group
float Ur,Ui,Wr,Wi,temp;
```

```
/*3.3.2.4.1  loop for each state*/

for(int stage=1 ; stage<=m ; stage++)
{
        BTFly_size          = (int)Math.Pow(2,stage);
        BTFly_step_to_pair  = BTFly_size/2;

        Ur=1.0f;
        Ui=0.0f;

/*3.3.2.4.2  prepare Wn on the current state */

        Wr=(float)Math.Cos(2*Math.PI/BTFly_size);
        Wi=(float)Math.Sin(2*Math.PI/BTFly_size);

/*3.3.2.4.3  loop for each butterfly group in current state */
        // for sample, 3 stage (8 data),
        //      state 1 has 4 groups: butterfly size =2 wing,
        //      state 2 has 2 groups: butterfly size =4 wings,
        //      state 3 has 1 groups: butterfly size =8 wings.
        for(BTFlys_group_pointer=1;
            BTFlys_group_pointer<=BTFly_step_to_pair ;
            BTFlys_group_pointer++                          )
        {
            index_a = BTFlys_group_pointer;

/*3.3.2.4.4  sub-sub loop for each butterfly in current group */
            for( ;index_a <= NumPoint; )
            {
                index_b = index_a + BTFly_step_to_pair;
```

```
                    tmp_real = x[index_b,0]*Ur - x[index_b,1]*Ui;
                    tmp_imag = x[index_b,1]*Ur + x[index_b,0]*Ui;

                    x[index_b,0] = x[index_a,0] - tmp_real;
                    x[index_b,1] = x[index_a,1] - tmp_imag;

                    x[index_a,0] = x[index_a,0] + tmp_real;
                    x[index_a,1] = x[index_a,1] + tmp_imag;

                    index_a += BTFly_size;
                }
                temp   = Ur*Wr - Ui*Wi;
                Ui     = Ui*Wr + Ur*Wi;
                Ur     = temp;
        }
}
```

3.3.2.5 Compute magnitude from complex result x.

```
for(int r=0 ; r<=FrequencyResolution ; r++)
{
                        //sqrt( real^2 * imagine^2 )
        result[r]= (float)Math.Sqrt( x[r,0]^2 + x[r,1]^2 );
}
```

Once the Gaussian window function was applied to the input data, the FFT will be changed to Gabor transform. The giving result of Gabor Transform shows that the ringing noise effect is decreased. The process to apply Gaussian window function to the input data is mentioned below.

$$STFT_{X(\omega)} = \int_{t} [x(t) \cdot \omega^{*}(t - t')] \cdot e^{-j2\pi ft} dt$$

$$DiscreteSTFT_{X(n,r)} = \sum_{m=-\infty}^{\infty} x[n] w[n-m] e^{-j(\frac{2\pi}{N} r)m}$$

From equation above, Gaussian window array, w[n-m], were applied to FFT equation. In this research, the algorithm of STFT will be applied from FFT algorithm by adding one process over. So, the STFT algorithm will be;

- Read in the block of input samples
- Apply analysis Gaussian window
- Perform FFT

The STFT flowchart can be adjusted from FFT flowchart as shown below.

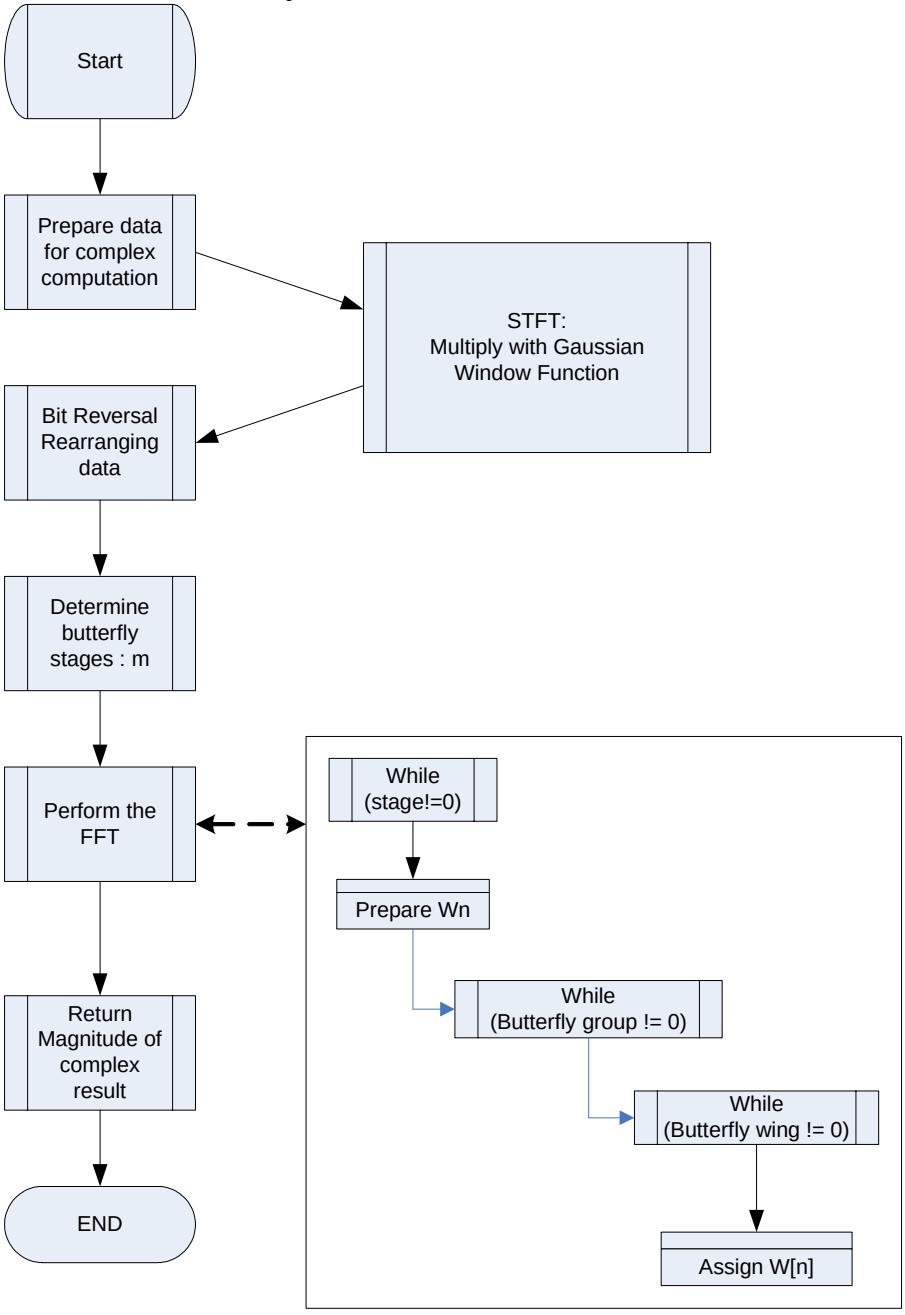


Figure 39. Flowchart of STFT

3.3.3 Wavelet Transform

In this research, the data in whole sampling will be divided for performing wavelet transform second by second. The section displays the source code for preparing mother wavelet and for performing wavelet transform in the research.

To generate Haar Mother Wavelet, see the code below.

```
h[0]= (float)(1/Math.Sqrt(2));
h[1]=(float)(1/Math.Sqrt(2));
g[0]=(float)(1/Math.Sqrt(2));
g[1]=(float)(-1/Math.Sqrt(2));
```

Once the low pass filter, h[], and high pass filter, g[], are prepared, the process of Haar wavelet transform can be start by construction the filter tree as shown in figure below.

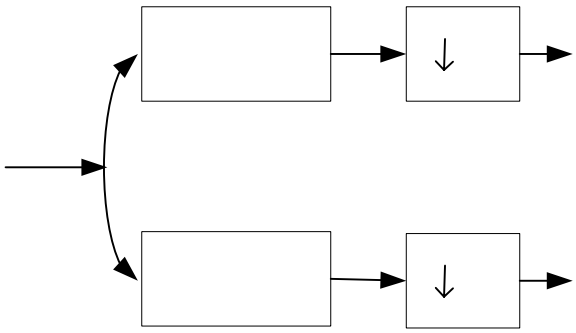


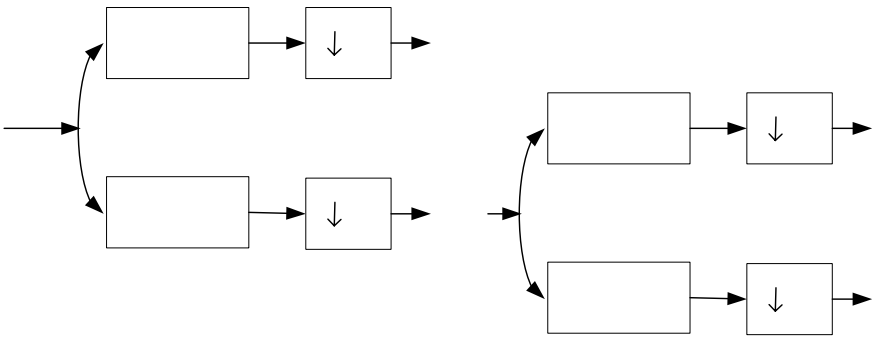
Figure 39. Wavelet analysis filter bank.

The filter tree for Haar wavelet transform can be written as following code.

```
void HaarWT(float  [] Vin, filter [] f, float [] Wout, float [] Vout)
{
        for(t=2;t<=Vin.Lenght;t+=2)
        {
                Wout[t/2]+=g[0]*Vin[t-1] + g[1]*Vin[t];
                Vout[t/2]+=h[0]*Vin[t-1] + h[1]*Vin[t];
        }
}
```

h[

To display more resolutions of results, the filter tree can be connected to cascade tree. And then output from low pass filter will be decomposed until the scale reach to their minimum scale, or equal zero.



$$
\begin{aligned}
V_0 &= V_{-1} + W_{-1} \\
&= V_{-2} + W_{-2} + W_{-1} \\
&= V_{-3} + W_{-3} + W_{-2} + W_{-1} \\
&= V_{-4} + W_{-4} + W_{-3} + W_{-2} + W_{-1}
\end{aligned}
$$

Figure 40. Multi resolution Wavelet filters bank.

h[ ] 2

To perform wavelet transform, the filter tree can be cascaded by adjusting the above code, the new algorithm will also enable for any length of mother wavelet array. The main loop in wavelet codes were adjusted as below.

Vin

```
for (  int scale = SamplingRate/2  ;  scale>=0  ;  scale/=2  )
//64,32,16,8,4,2,0(1,1) at Sampling Rate 128 samples/second
{                                                          g[ ]  2
        int scale_size = scale;
        if(scale==0) scale_size = 1;
        for(  int t=0  ;  t < scale_size  ;  t++  ) // step of data array
        {
                for(int wt_i=0; wt_i <h.Length ; wt_i++)
                {
                        Wout [t] +=     g[wt_i]* Vin [(t*2)+wt_i];
                        Vout [t+1] += h[wt_i]* Vin [(t*2)+wt_i];
                }
        }
```

```
        Vin = Vout;
        result[Math.Log(scale,2)] = Wout;
}
```

An important point to be discussed is how to choose the mother functions to be compared with the signal. In principle, the wavelet function should have a certain shape to localize in the original signal. However, due to mathematical restrictions, not every function can be used as a wavelet. Then, one criterion for choosing the wavelet function is that it looks similar to the patterns of the original signal. In this respect, B-Spline functions seem suitable for decomposing EEG signal. Decomposition filter corresponding to quadratic B-Spline mother are shown in the table below.

Table 1. Decomposition Filter for quadratic B-Spline Wavelet (9)

h[]	g[]
0.00157f,	-0.00388f,
0.01909f,	-0.031416f,
-0.00503f,	0.00901f,
-0.0444f,	0.07933f,
0.01165f,	-0.02096f,
0.10328f,	-0.18408f,
-0.02593f,	0.04977f,
-0.24373f,	0.42390f,
0.03398f,	-0.14034f,
0.65523f,	-0.90044f,
0.65523f,	0.90044f,
0.03398f,	0.14034f,
-0.24373f,	-0.42390f,
-0.02593f,	-0.04977f,
0.10328f,	0.18408f,
0.01165f,	0.02096f,
-0.0444f,	-0.07933f,
-0.00503f,	-0.00901f,
0.01909f,	0.03416f,
0.00157f	0.00388f

CHAPTER IV
RESULTS

This section contains the result of the transform function, EEG spike detection, 2D and 3D topographic with the program interface. Figures below show the result program with the detection of 3 Hz spike from FFT and B-Spline wavelet transform.

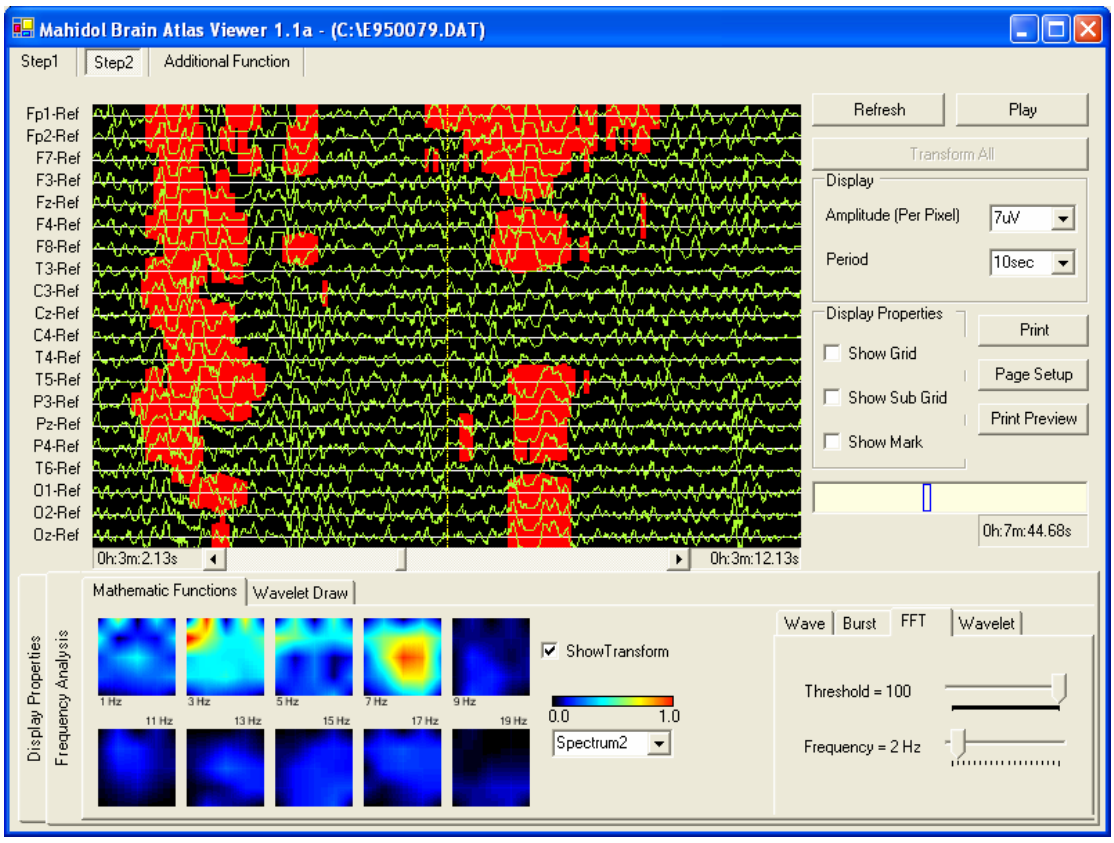


Figure 41. result program with the spike detection from FFT

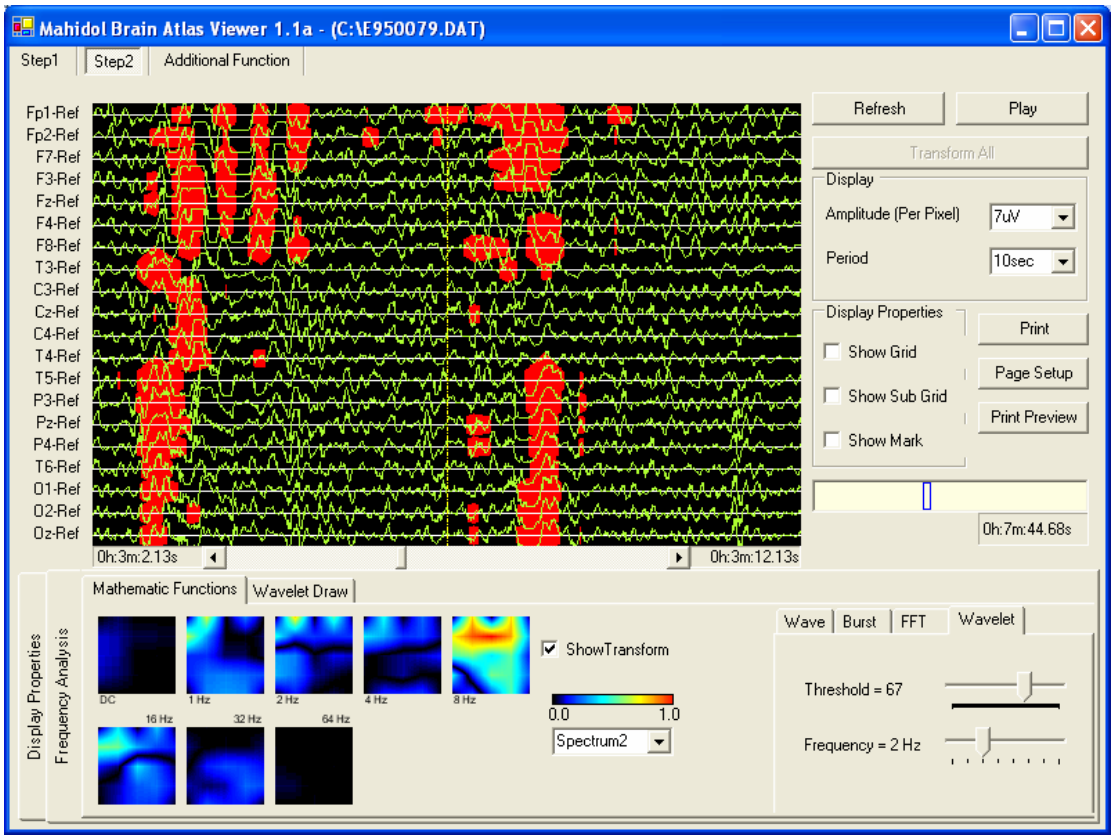


Figure 42. result program with the spike detection from Wavelet

4.1 Main Program

The final implemented program contains three major tab pages for using step by step. Page-Step1 shows the file opening button and information of patient. Page-Step 2 will show the display area for EEG signal of patient in file and provide 3 transform methods. The spike detection will show the result of detection on the main display per each electrode. The user can see the position which spike were detected and total spike count on whole data. Page-Step 3 will show the 3 dimension topographic mapping of the EEG signal

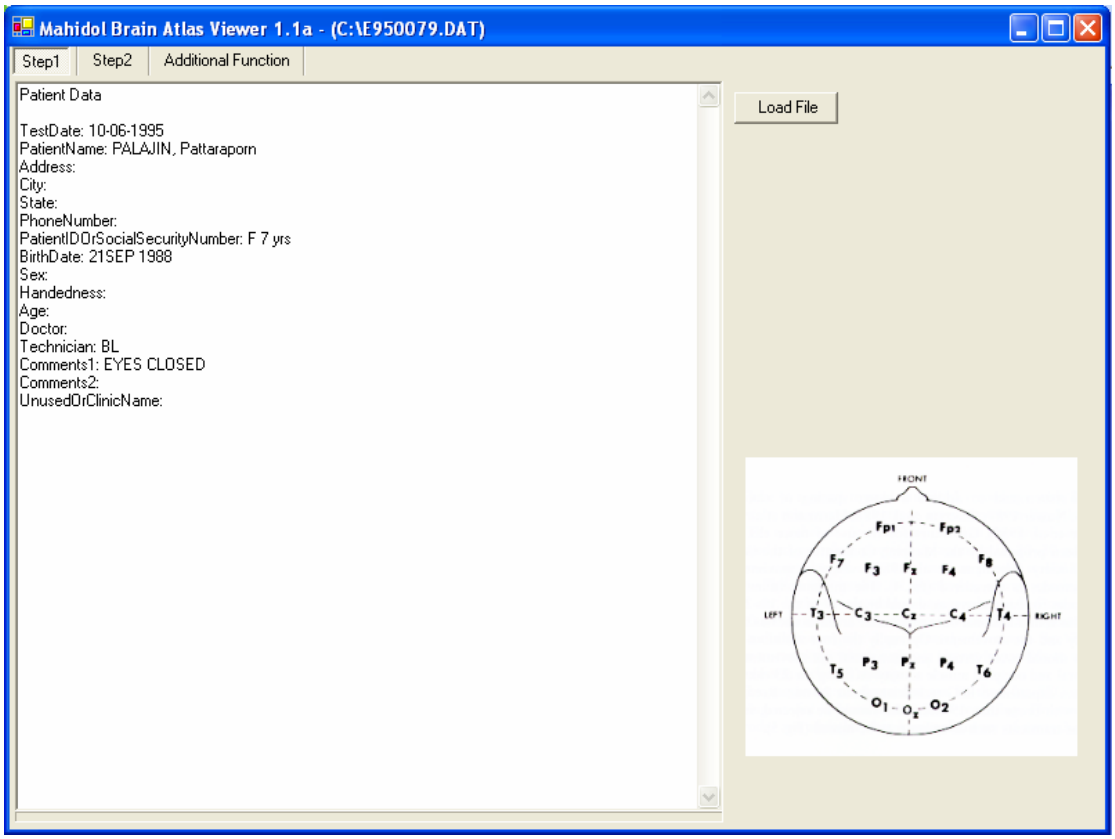


Figure 43. Main Window Program

4.2 The patient information display

On page-step 1, the header of EEG file, containing the information of patient and measurement parameter, is displayed in this area. The information consists of the patient name, age, sex, testing date and other needed parameters.

4.3 3D Topographic

Figure below show 3D FFT topographic map which was acquired by abnormal patient who has a detected spike at 3 Hz. The 3D display of animation EEG topographic of signal behavior can let EEGer know and accurate dysfunction location.

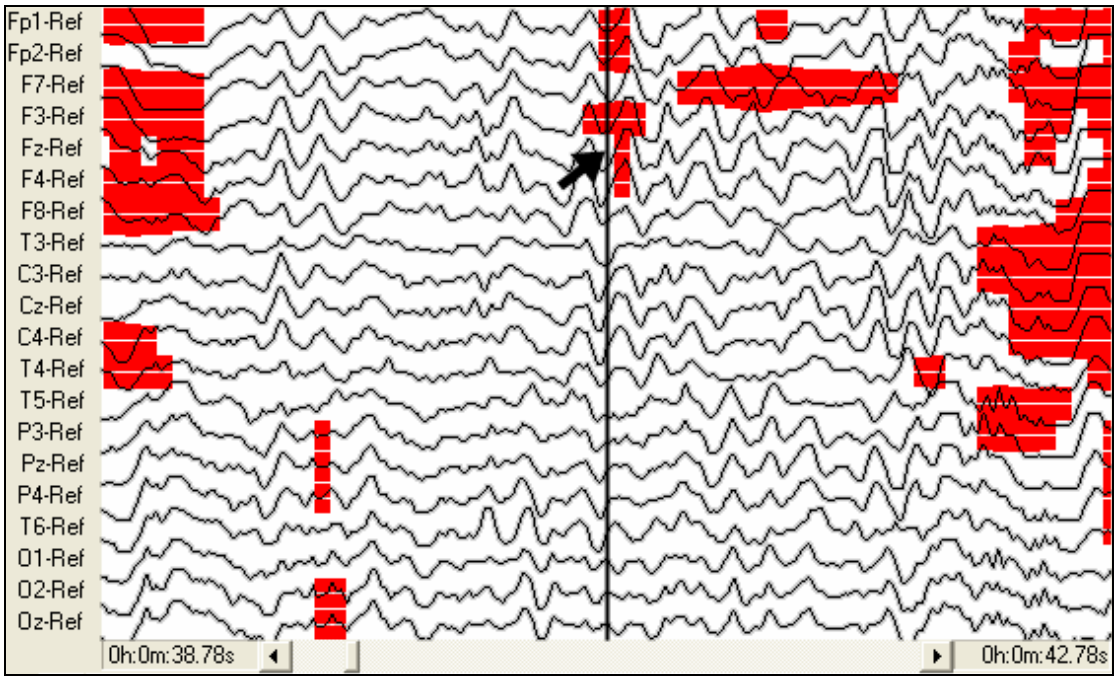


Figure 44. EEG Signals and the bar indicated the plotting point of topographic.

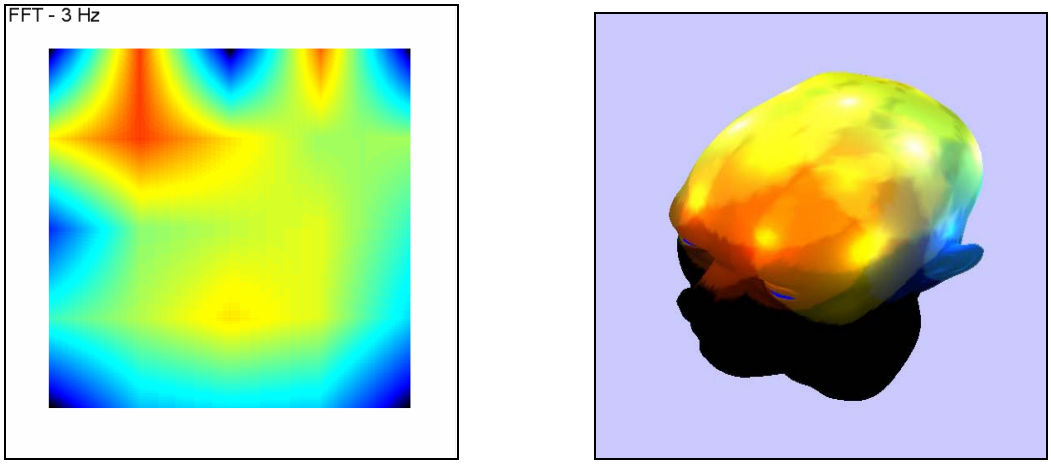


Figure 45. Topographic of FFT EEG Signals, and 3D mapping, 3Hz.

4.4 EEG Signal Transformation and Spike Detection

This section contains the signal transformation from abnormal patient who has a detected spike, 6 Hz. The results from cross correlation to sinusoidal wave and burst, STFT and B-Spline wavelet analysis are shown below.

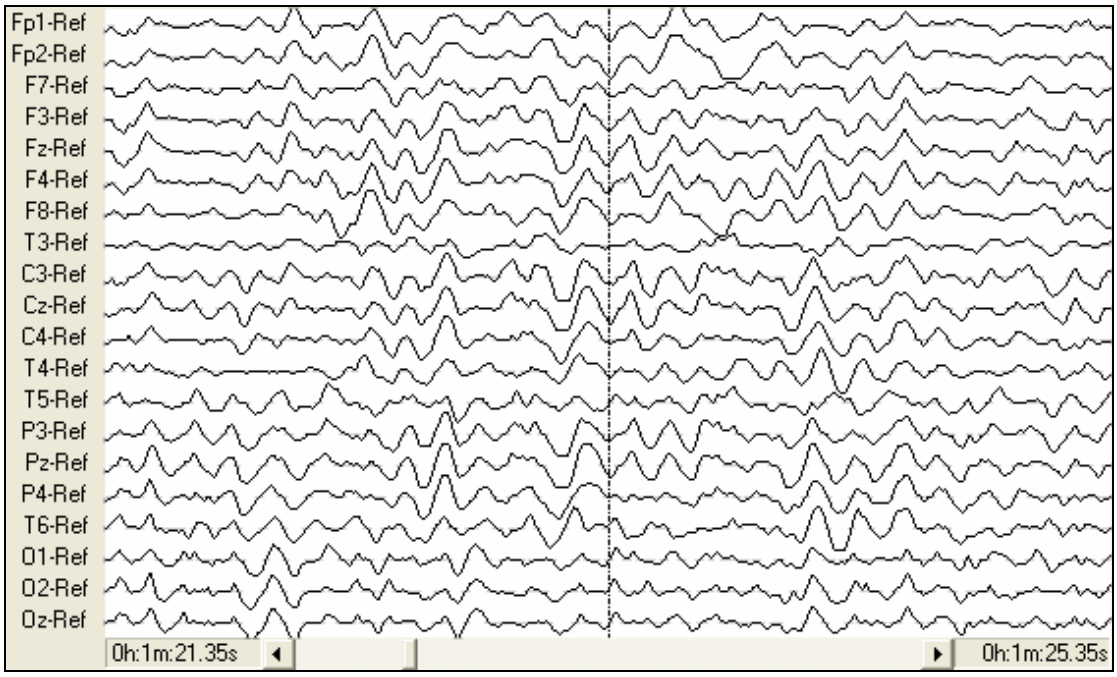


Figure 46. EEG Signal with 6Hz Wave.

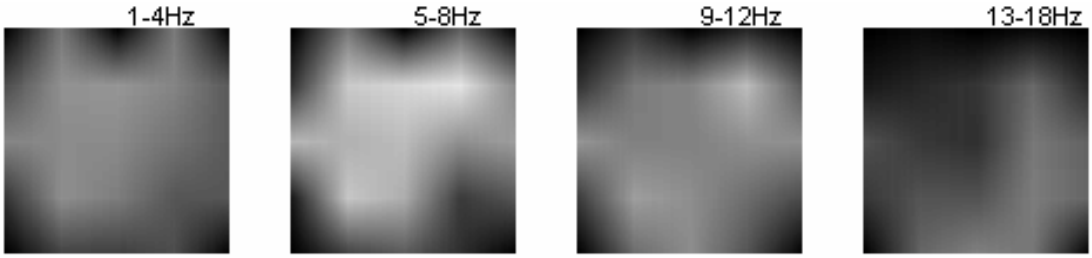


Figure 47. Cross Correlation to Sinusoidal Wave

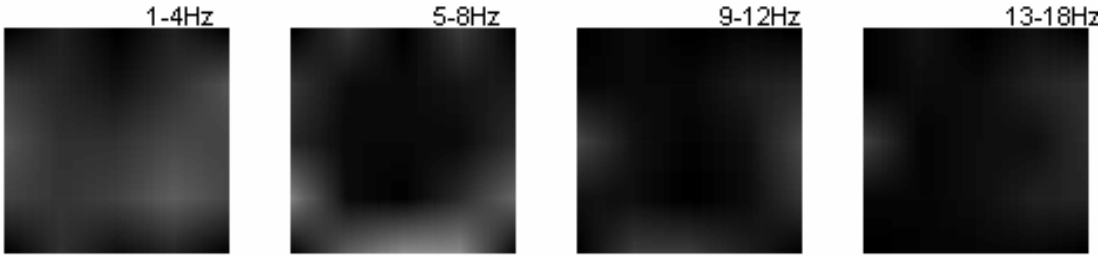


Figure 48. Cross Correlation to Wave Burst

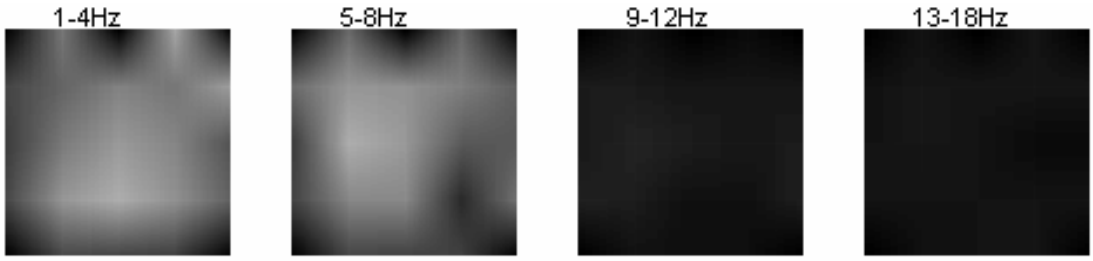


Figure 49. Short Time Fourier Transform

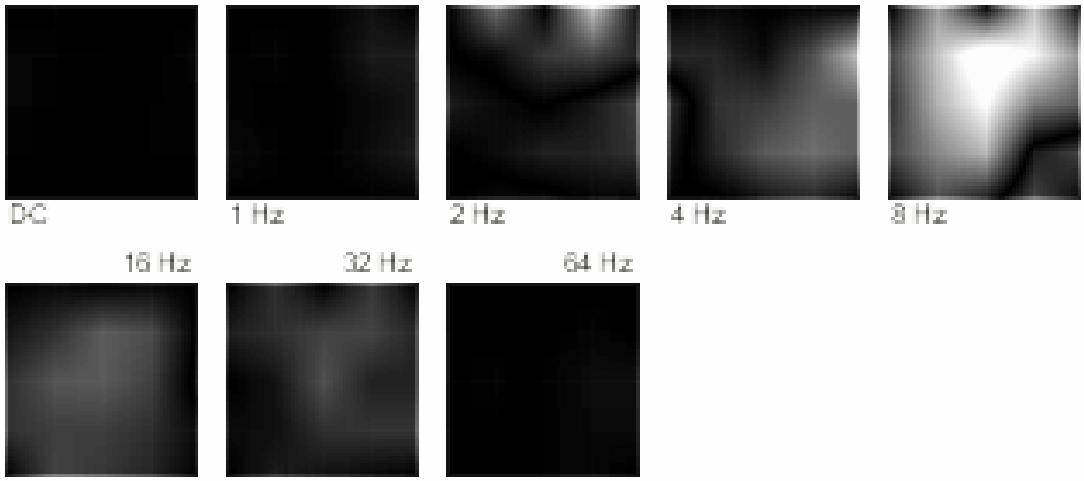


Figure 50. B-Spilne Wavelet

The figure below shows the conventional method, FFT topography, of 6 Hz, which is mapped in 2D and 3D. The result display the 6Hz signal origin is located at electrode F3.

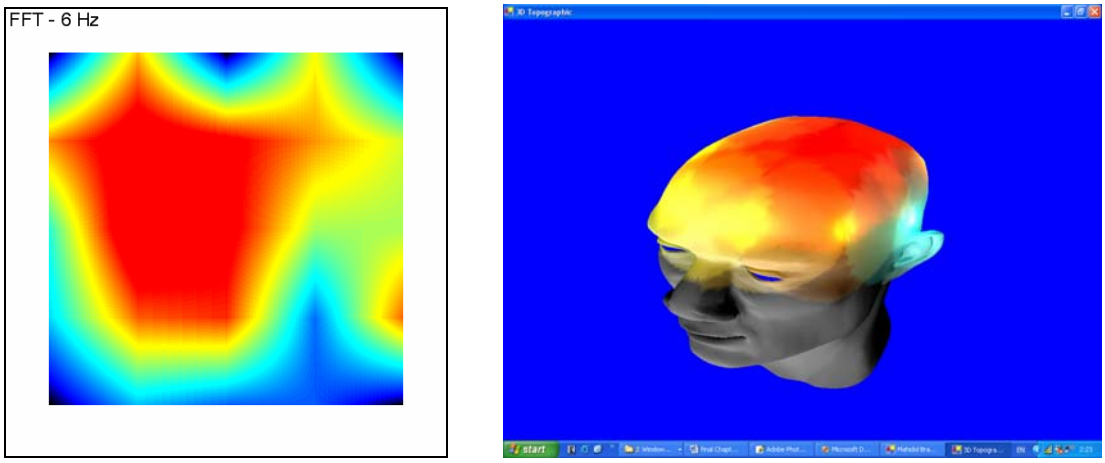


Figure 51. Topographic of FFT EEG Signals, and 3D mapping, 6Hz.

And the detection of 6Hz spike of each method are in the following figures.

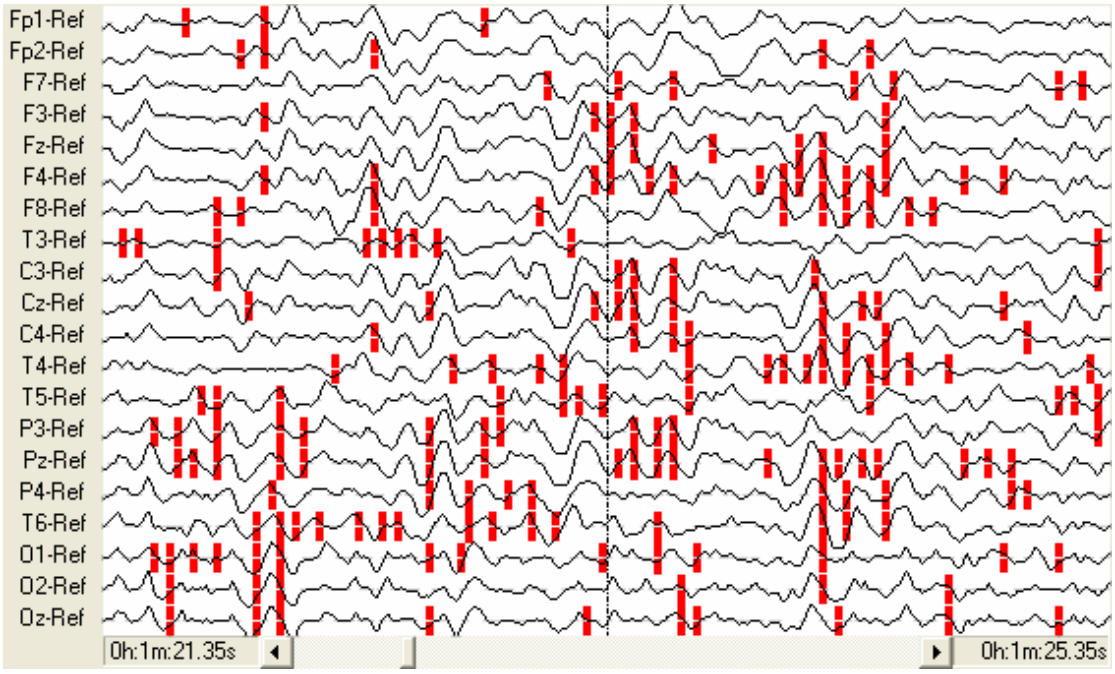


Figure 52. 6Hz Wave Detection by Cross Correlation to 6Hz Sinusoidal wave.

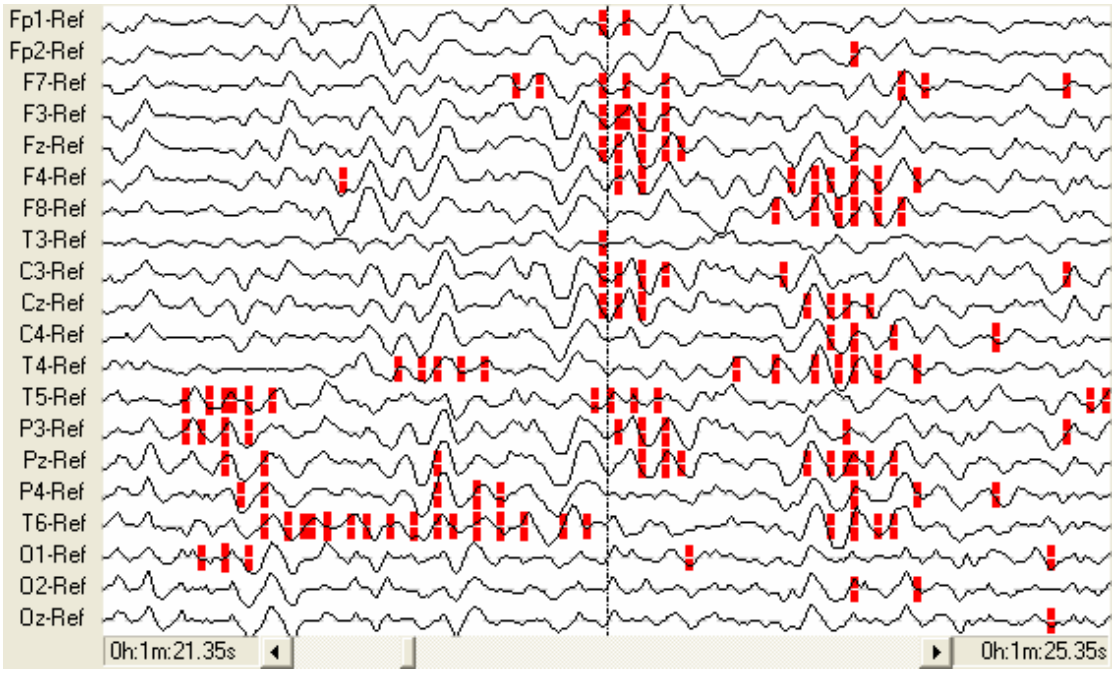


Figure 53. 6Hz Waves Detection by Cross Correlation to 6Hz Sinusoidal Waves (Burst).

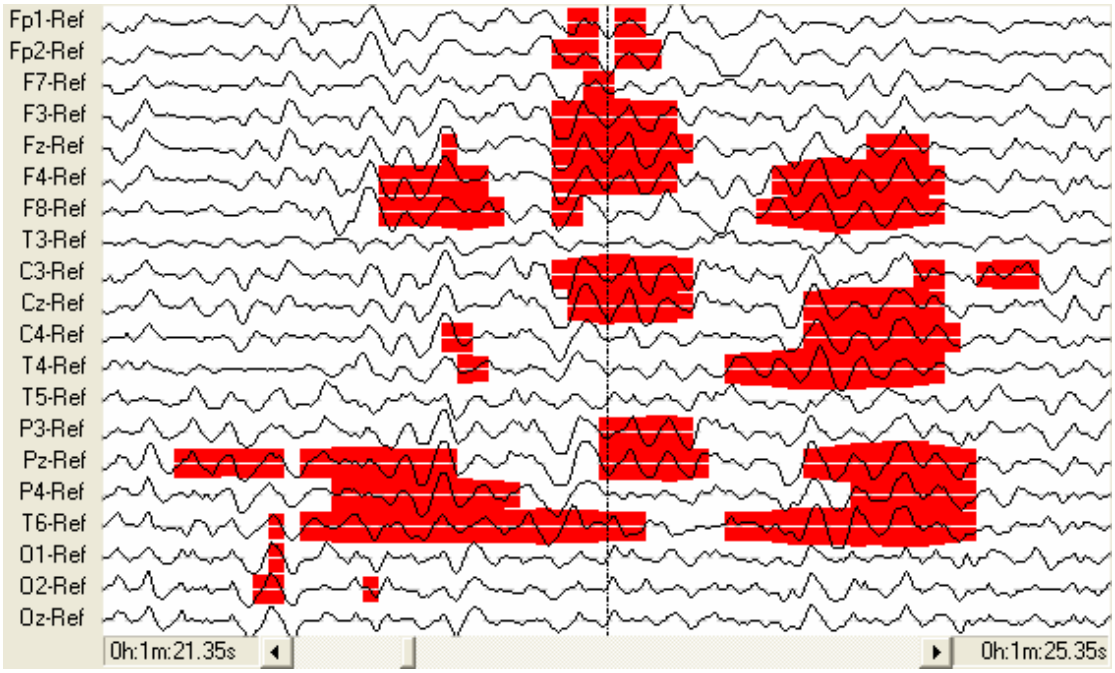


Figure 54. 6Hz Wave Detection by STFT (Gabor Transform).

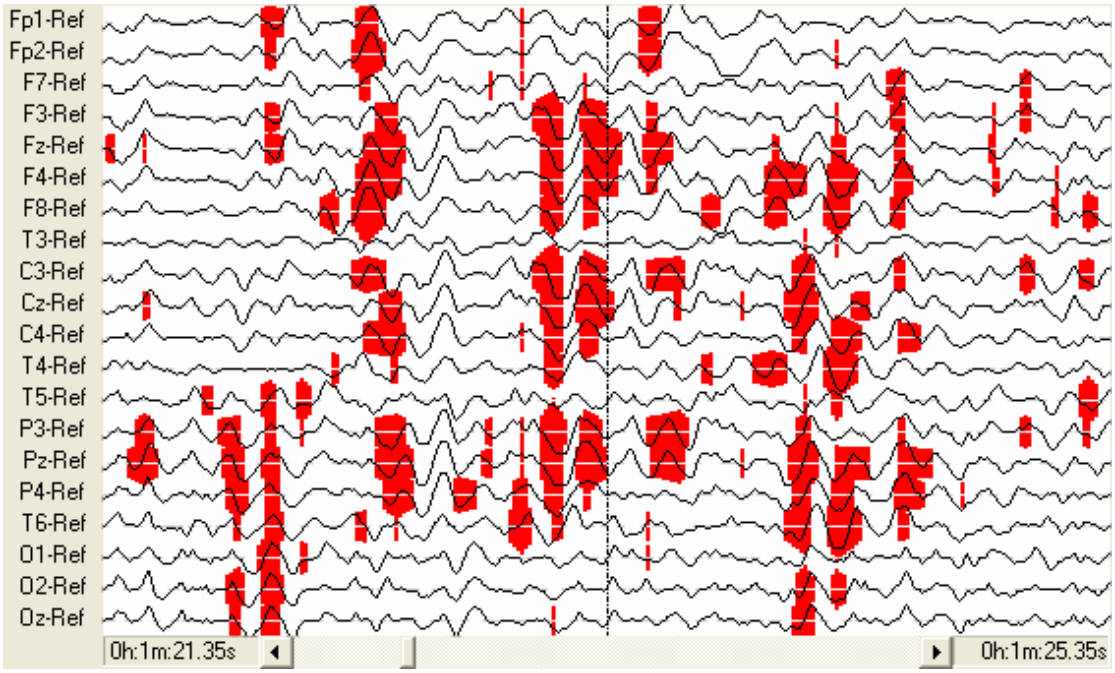


Figure 55. 8Hz (nearest to 6 Hz) Wave Detection by B-Spline Wavelet Transform

The Wavelet Analysis applied to electrode F3 are shown below.

Figure 56. Haar Wavelet Analysis of F3 at time = 1m:23sec.35

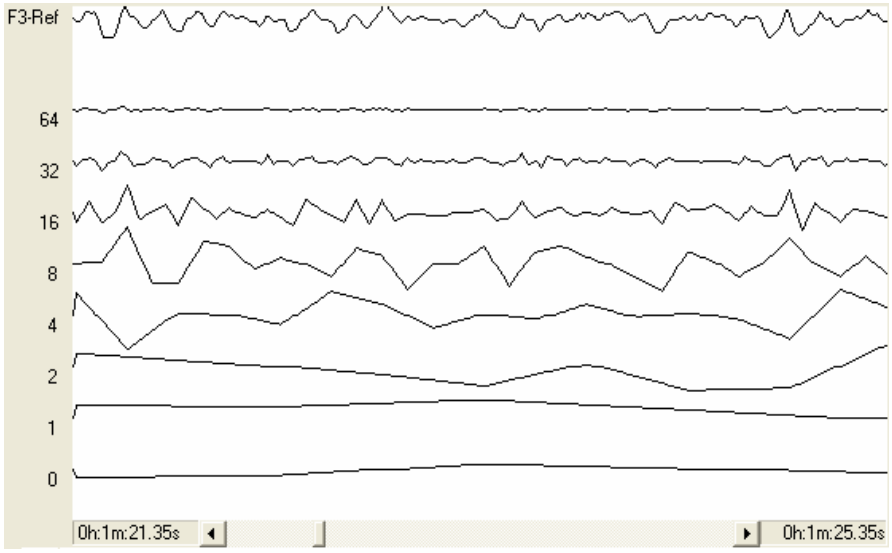


Figure 57. Haar Wavelet Decomposition of F3 at time = 1m:23sec.35

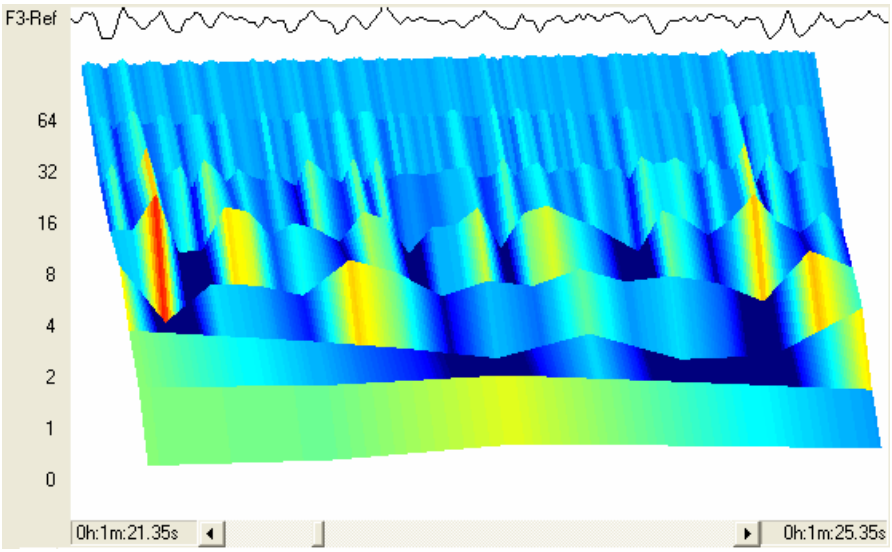


Figure 58. 3D Haar Wavelet Decomposition of F3 at time = 1m:23sec.35

Figure 59. B-Spline Wavelet Analysis of F3 at time = 1m:23sec.35

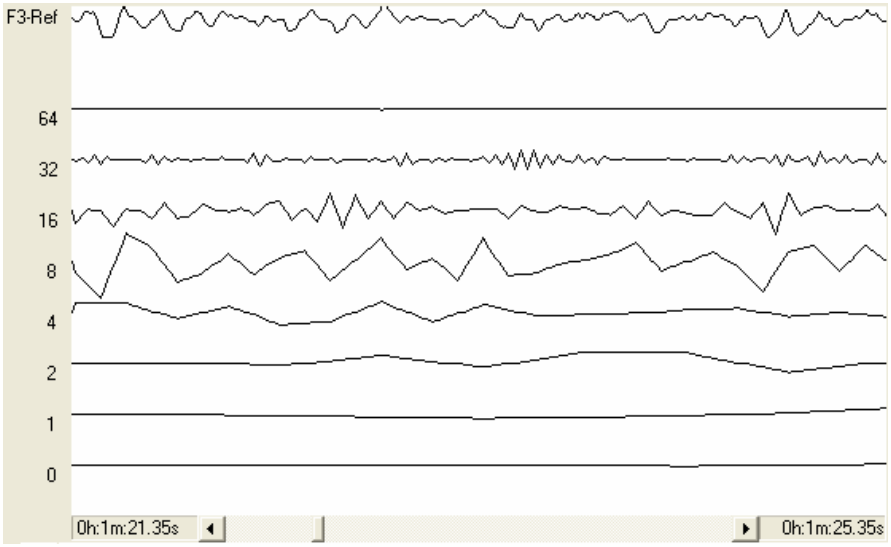


Figure 60. B-Spline Wavelet Decomposition of F3 at time = 1m:23sec.35

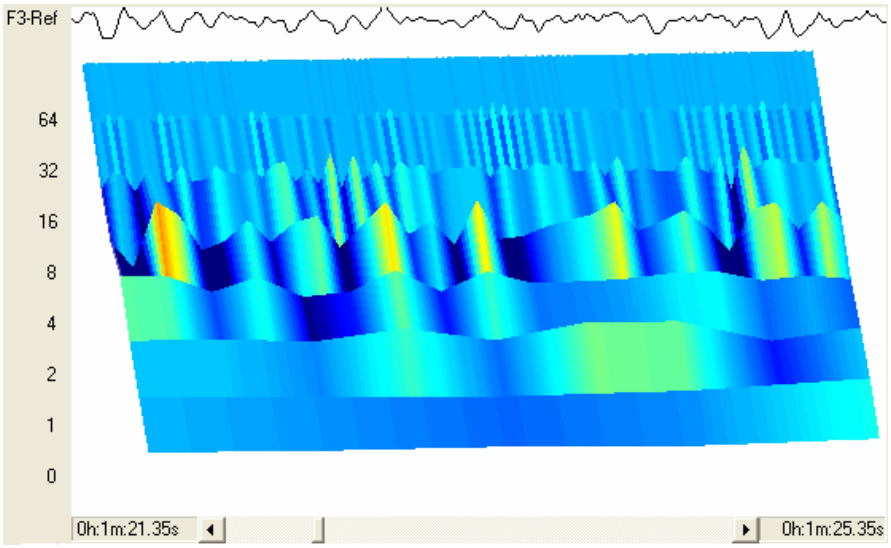


Figure 61. 3D B-Spline Wavelet Decomposition of F3 at time = 1m:23sec.35

CHAPTER VI
CONCLUSION

The use of the B-Splines wavelet analysis should be operated together with conventional FFT, the clinical patient history and the visual assessment of the EEG, to obtain a better understanding of its dynamic. Other mother wavelet could be attempted to extract more information from brain potential recording in future study.

The topographic mapping onto 3D head model using 20 standard light-objects from DirectX9.0c can be processed on almost 3D accelerator card on market and show high resolution and high speed processing time. Anyway, the 3D head model can be presented more accurately in future study by adding some features for different head model, different rendering method and freely 3D electrode position adjustment for each patient.

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APPENDIX

APPENDIX
BRAIN ATLAS EEG FILE HEADER FORMAT

CEEGRAPH / BRAIN ATLAS EEG FILE HEADER FORMAT (Updated 07/10/91, 02/27/92)

OFFSET	LENGTH	TYPE	DESCRIPTION
0	1	Byte	Number of Bytes per data point (EP and FFT files only)
1	1	Byte	Number of 128 blocks for header If 8 then Header is 1024 bytes If 13 then Header is 1664 bytes If 15 then Header is 1920 bytes If 17 then Header is 2176 bytes
2	2	Word	Version Number (x 100)
4	1	Byte	A/D Size (8 = 8 bit, 11 = 11 bit)
5	1	Byte	Amplifier type 0= External EEG Machine 1= Biologic 4 Channel Amps/ Preamps in an expansion bus. 2= Hybrid A Amplifiers, 20 chan. headbox 3= Hybrid B Amplifiers, 20 chan. headbox 4= Hybrid A Amplifiers,EMG Combo headbox 5= Hybrid B Amplifiers,EMG Combo headbox 6= Hybrid A Amplifiers 32 Chan Switch headbox 7= Hybrid B Amplifiers 32 Chan Switch headbox 8= Hybrid A Amplifiers, 22 chan. headbox 9= Hybrid B Amplifiers, 22 chan. headbox 10= Bio-logic Gamma Integrated Amps / Headbox
6	2	Word	Model Number
8	1	Byte	Sub-version number x.xx#
9	1	Byte	Misc flags
10	1	Byte	Misc flags
11	4	DWord	Byte offset to Data in File (Integer)
15	4	DWord	unused (Byte offset to Next Header in File)
19	4	DWord	unused (Byte offset to Prev Header in File)
23	1	Byte	unused

CEEGRAPH / BRAIN ATLAS FILE HEADER FORMAT Spring 1991

OFFSET	LENGTH	TYPE	DESCRIPTION
PATIENT INFORMATION			
24	10	String	Test Date
34	25	String	Patient Name
59	25	String	Address
84	20	String	City
104	2	String	State
106	20	String	Phone #
126	11	String	Patient ID# or Social Security Number
137	10	String	Birth Date
147	1	String	Sex
148	2	String	Handedness
150	3	String	Age
153	19	String	Doctor
172	25	String	Technician
197	35	String	Comments (1)
232	35	String	Comments (2)
267	40	String	unused or Clinic name
FILE INFORMATION			
307	1	String	Filename Prefix "T"= topo. EP, "F"=FFT "E"= raw EEG, "S"=EP Statistical "G" = FFT Statisical
308	7	String	Filename (last 7 letters)
315	10	N/A	
325	5	String	Low Filter Setting, External Machine

330	5	String	High Filter Setting, External Machine
335	6	String	Reference Electrode, External Machine
341	5	String	Ground Electrode, External Machine
346	1	Byte	Number of channels actually collected.
347	9	N/A	
356	1	Byte	Number of EEG channels saved in file.
357	9	N/A	

CEEGRAPH / BRAIN ATLAS EEG FILE HEADER FORMAT Spring 1991

OFFSET	LENGTH	TYPE	DESCRIPTION
BRAIN ATLAS E.P. PARAMETERS			
367	42	N/A	
409	1	Byte	P300 ratio (If 0, then identifies CSA data file)
410	2	N/A	
412	3	N/A	(data_mode, display_scale, channel_total)
415	2	Word	Time duration (in msec.) for a sample set (256 points) of Banked EP data. Translates into SAMPLE RATE as follows: 1280 = 200 Hz sample rate 2000 = 128 Hz sample rate 2560 = 100 Hz sample rate 4000 = 64 Hz sample rate 1000 = 256 Hz sample rate
417	6	N/A	
423	1	Byte	EEG Machine polarity / Invert data flag 0= Positive up (don't invert) -1= Negative up (invert)
424	1	Byte	Program Code for file 0 = Brain Atlas 1 = CSA 2 = Sleep (NOT CONFIRMED) 3 = Ceegraph / BioLogic Amps 4 = Ceegraph / External Amps
B.A. CALIBRATION PARAMETERS			
425	21*1	Byte	Brain Atlas calibration A/D width 200 microvolt peak-peak voltage Channels Fp1,Fpz,Fp2,...O1,Oz,O2
446	21*1	Byte	Brain Atlas calibration DC offsets Channels Fp1,Fpz,Fp2,...O1,Oz,O2
467	2	Word	Sensitivity of External EEG Machine in uV/mm
469	2	Word	Cal Signal voltage in microvolts (Cal Sensitivity of 10 uV/mm is assumed)

CEEGRAPH / BRAIN ATLAS EEG FILE HEADER FORMAT Spring 1991

OFFSET	LENGTH	TYPE	DESCRIPTION

B. A. STIMULATION PARAMETERS

471	129	N/A	EEG doesn't use stimulus information

AMPLIFIER PARAMETERS

600	2	Word	Nominal 200 uV value # which represents 200uV p-p from A-D External Amps = 192 (sensitivity of 10uV/mm assumed) Internal Amps = 204 (gain of 20000 assumed)
602	32*1	Byte	Gain Codes
634	1	Byte	Master Control Gain Code
635	1	Byte	

Table of Gain Codes:

Gain	Code
10	24
50	25
75	26
100	27
150	28
200	29
250	32
300	31
500	17
750	18
1000	19
1500	20
2000	21
2500	33
3000	23
5000	9
7500	10
10000	0
15000	12
20000	13
25000	34
30000	15
50000	1
75000	2
100000	3
150000	4
200000	5
250000	35
300000	7

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OFFSET	LENGTH	TYPE	DESCRIPTION
636	32*1	Byte	Low Pass Filter Codes
668	1	Byte	Master Control L.P.F Code
669	1	Byte	

Table of Low Pass Filter Codes:

Filter	Code
15 Hz	0
30 Hz	1
70 Hz	2
100 Hz	3

670	32*1	Byte	High Pass Filter Codes
702	1	Byte	Master Control H.P.F Code
703	1	Byte	

Table of High Pass Filter Codes:

Filter	Code
0.1 Hz	0
0.3 Hz	1
1 Hz	2
3 Hz	3

704	32*1	Byte	Notch Filter Codes
736	1	Byte	Master Control Notch Filter Code
737	1	Byte	

Table of Notch Filter Codes:

Filter	Code
In	0
Out	1

738	32*1	Byte	AC / DC Coupling Codes
770	1	Byte	Master Control AC / DC Coupling Code
771	1	Byte	(Codes not used at this time)

B R A I N A T L A S B A N K S P A R A M E T E R S

772	28	N/A	
800	32*1	Byte	Channel Interpolation Table

			0= Channel Interpolated (not collected) 1= Channel Collected
832	7	N/A	
839	4	Dword	Master Control Gain Value Long Integer Typical value = 20000
843	61	N/A	

CEEGRAPH / BRAIN ATLAS EEG FILE HEADER FORMAT Spring 1991

OFFSET	LENGTH	TYPE	DESCRIPTION
CEEGRAPH 8-Bit CALIBRATION PARAMETERS			
904	32*1	Byte	Ceegraph 8 bit calibration A/D width 200 microvolt peak-peak voltage Channels Fp1,Fp2,...O1,O2,Oz,X1,X2,A1,A2
936	32*1	Byte	Ceegraph 8 bit calibration DC offsets Channels Fp1,Fp2,...O1,O2,Oz,X1,X2,A1,A2
968	1	Byte	11 bit Ceegraph data flag 1 = 11 bits, otherwise 8 bits
969	55	N/A	
1024	640	N/A	
MONTAGE AREA for EEG			
1664	32*2	Bytes	Display Montage Format: Ch1 Active, Ch1 Ref Ch2 Active, Ch2 Ref.... 0= Fp1, 1= Fp2... 17= O1, 18= O2 19= Oz, 20= X1, 21= X2, 23= A1, 24= A2 -1 = Reference
1728	32*6	String	Channel Labels (if any) for Display Montage. Use instead of default jack names.
End of File Header in Brain Atlas versions prior to BA ver 2.345			
CEEGRAPH 11-Bit CALIBRATION PARAMETERS			
1920	32*2	Word	Ceegraph 11 bit calibration A/D width 200 microvolt peak-peak voltage Channels Fp1,Fp2,...O1,O2,Oz,X1,X2,A1,A2
1984	32*2	Word	Ceegraph 11 bit calibration DC offsets Channels Fp1,Fp2,...O1,O2,Oz,X1,X2,A1,A2

CEEGRAPH EXTERNAL CHANNEL JACK NAMES

2048	32*3	String	Jack Names (if different) for External EEG Machine
2144	32	N/A	
2176			Beginning of EEG Data in BA version 2.345

Ceegraph voltage formula:

INTERNAL AMPLIFIERS

Calib AD Width is an 8 bit unsigned integer in table at offset 904 (Ceegraph) or 425 (BA)
Calib DC Value is an 8 bit unsigned integer in table at offset 936 (Ceegraph) or 446 (BA)
Gain is in a table at offset 602. Code must be translated to actual gain.

uv per bit = (200.0 / Calib AD Width) * (20000 / Gain)

DC Offset Voltage = (Calib DC Value - 128) * (Gain / 300000) * uv per bit

Data Value = (AD value - 128) * uv per bit) + DC Offset Voltage

EXTERNAL AMPLIFIERS

Cal signal Voltage is a 16 bit integer at file header offset 469
Calib AD Width is an 8 bit unsigned integer in table at offset 904
Calib DC Value is an 8 bit unsigned integer in table at offset 936
Gain is in a table at offset 602. Code must be translated to actual gain.

uv per bit = ((2 * Cal signal Voltage) / Calib AD Width) * (20000 / Gain)

DC Offset Voltage = (Calib DC Value - 128) * uv per bit

Data Value = (AD value - 128) * uv per bit) + DC Offset Voltage

NOTES: Differences between Ceegraph and Brain Atlas files

Brain Atlas Calibration values cannot be used, because there is only room for 21 values for Gain and DC.
Use Ceegraph Calibration values at byte offsets 904 and 936.
Bear in mind that Brain Atlas stores values for Fpz as channel #2, while Ceegraph does not store an Fpz value; in Ceegraph, Fp2 is the channel #2, and F7 is channel #3 as opposed to channel #4 in a Brain Atlas file, etc..
Also, Ceegraph stores the O2 and Oz calibration values in the order O2 = channel #19 , Oz = channel #20 ; Brain Atlas stores the values as O2 = channel #19, Oz = channel #20.
Channels #21 and #22 are the values for X1 and X2 respectively.

For Ceegraph files, the EEG Data itself will be 22 or 24 bytes per sample set, as opposed to 19 or 20 bytes per sample set.
The channels are saved in the same order as Brain Atlas; The additional channels , X1, X2, A1, and A2 , are saved as channels 21-24.
Note that having a header length of 2176 bytes does not necessarily indicate that a data file has 22 or 24 channels.

The EEG Channel Count field at byte # 356 in the header indicates the number of EEG channels saved in file.

Files recorded on an external EEG machine are not forced to save the channels Fp1,Fp2,... O1,O2,Oz,X1,X2,A1,A2 in that order. If the EEG machine is set up differently, the correct names for the collected channels will be saved at byte offset 2048 (3 characters per name). If the 3 characters are blank or null, then the default label for that channel should be used.
No channels are interpolated and saved in Ceegraph as is the case in Brain Atlas.

The file header is 2176 bytes long, as opposed to 1920 or 1664 bytes. New or changed fields in the file header include:

Byte 147 : Sex 'M' or 'F'

Byte 148 : Handedness 'RT' 'LT' 'AM'

Byte 150 : Age

Byte 153 : Doctor - started at Byte 147 in old files; however, this data could not be entered via the BA program.

Bytes 425, 446 : Brain Atlas calibration values. Values are stored for Fp1,Fpz,Fp2...O1,Oz,O2 for Brain Atlas compatibility.

Bytes 904, 936 : Ceegraph calibration values. Values are stored for Fp1,Fp2...O1,O2,Oz,X1,X2 .
These calibration values must be used in order to derive voltages for X1 and X2.

Byte 968 : 11 bit Ceegraph data file if equal to 1.
Information about 11 / 12 bit data file translation is not available at this time.

Bytes 1920,1984 : Ceegraph 11 bit calibration values.
Information about 11 / 12 bit data file translation is not available at this time.

Bytes 2048,2144 : External EEG Machine Jack Names
3 letter labels that name the channels collected if the channels are different from Fp1,Fp2, etc.

BIOGRAPHY

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